Generic Detector R&D Program

Status & Plans

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May 19, 2010

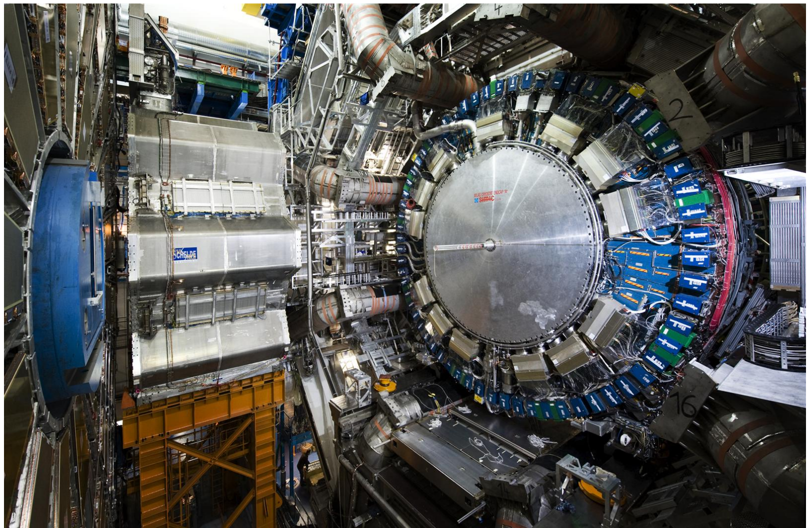
BROOKHAVEN NATIONAL LABORATORY

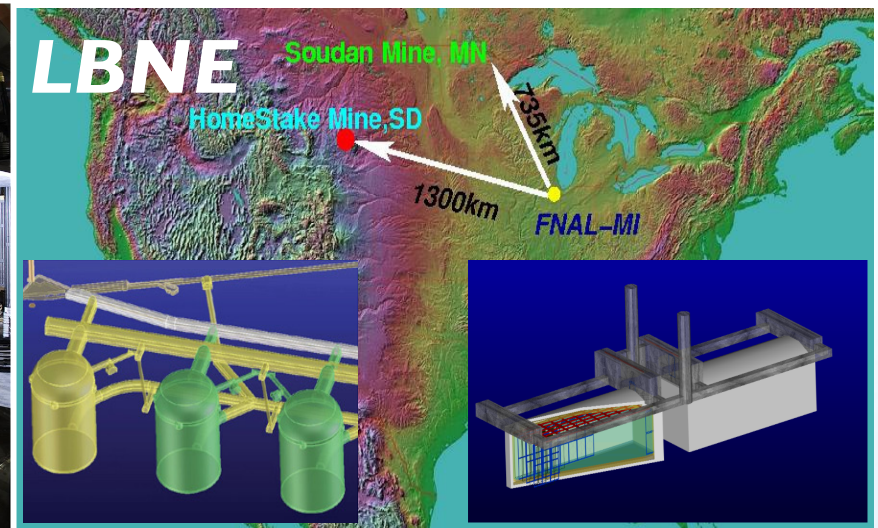
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Introduction

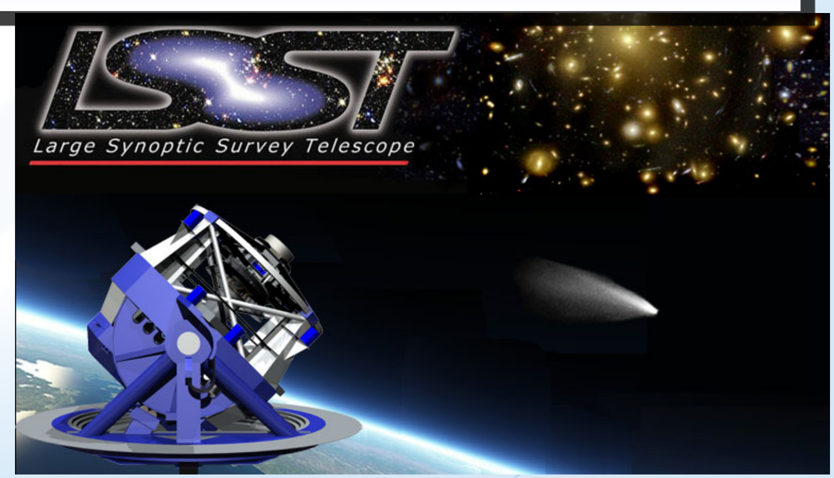
Atlas



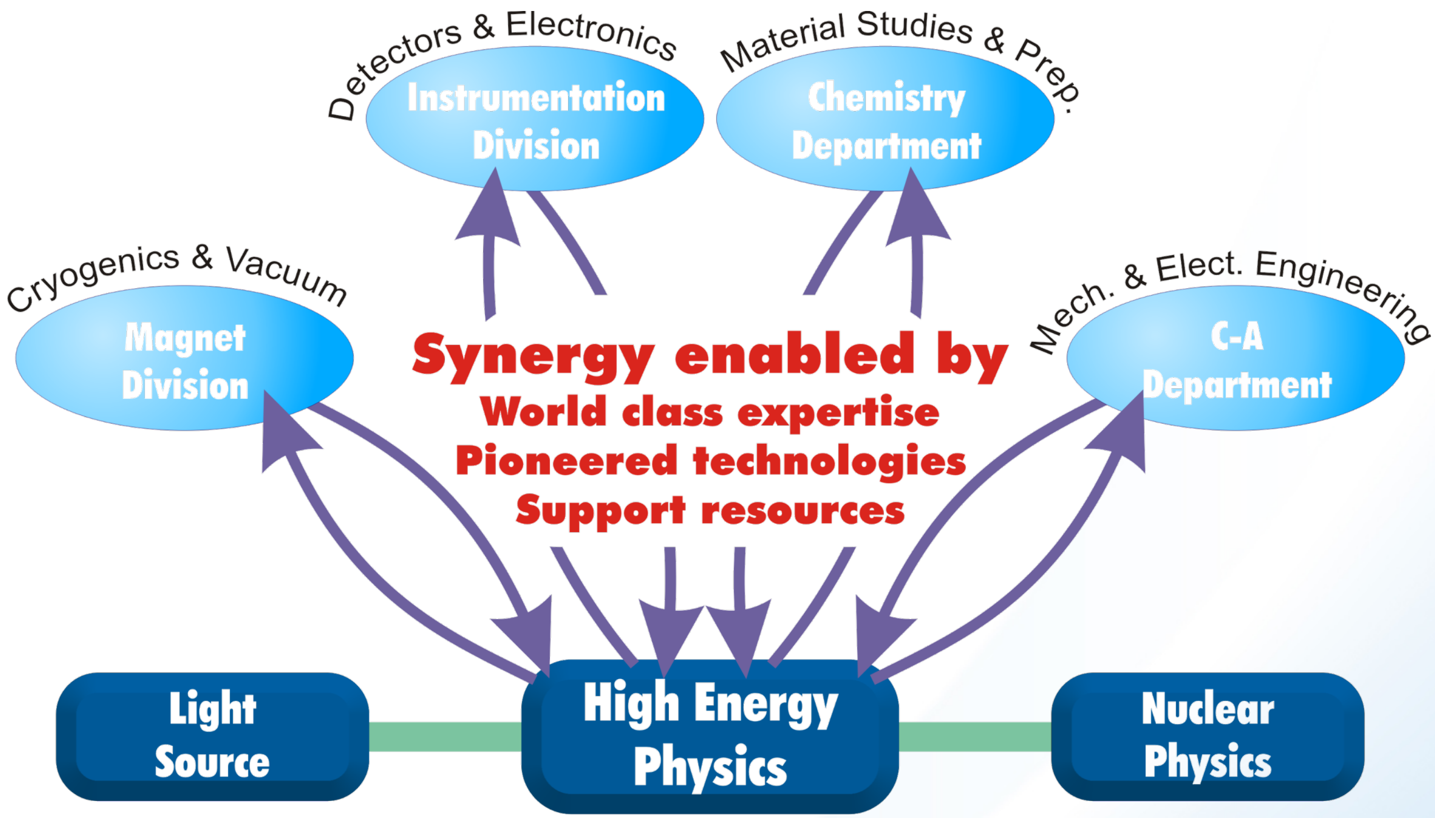


Generic detector R&D program at BNL aims to develop new or improved capabilities and to create leadership roles in the present and future generation of experiments in all the major frontiers of the U.S. HEP Program:

- Energy Frontier (e.g. D0 at Tevatron, ATLAS at LHC, ILC)
- Intensity Frontier (e.g. Daya Bay, microBooNE, LBNE)
- Cosmic Frontier (e.g. LSST)



One Lab – Many Strengths



Generic detector R&D is carried out in collaboration with the Instrumentation Division and depends on the Division fabrication and testing facilities in sensors, electronics, detector systems, and data acquisition

Outline

KA15 Support
None

Sensors and Electronics

- ✓Silicon Sensors
- ✓Sensors for the "cosmic frontier"
- ✓Photodetectors
- ✓Electronics and signal processing

Detector Systems

- ✓Long drift noble liquid detectors
- ✓Charge and light transport in LAr
- ✓Micro-pattern gas detectors (bulk icromegas)
- ✓Metal-loaded liquid scintillators

Data Acquisition Systems

- ✓Reconfigurable computing

Silicon Detector Development Capabilities for HEP

- *KA15 core currently supported scientific personnel: D. Lynn, W. Chen*
- *Other scientific and engineering personnel: Z. Li, J. Kierstead*

- Instrumentation Division's Semiconductor Detector Development and Processing Lab (SDDPL) is the only US R&D center for development and production of silicon sensors for HEP applications

Focus

- New detector concepts
- Radiation hard materials
- Defect analysis
- New defect analysis techniques

Infrastructure

- 600 square feet fully qualified class 100 cleanroom
- Design and process simulation
- All detector processing steps (with exception of ion implantation)
- 2D and 3D detector simulation
- History of design and development of detectors for HEP experiments

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Radiation Hard Silicon Sensors for HEP

BNL has 18 years of pioneering radiation hard silicon sensor research

Basic material research

- ✓ introduction of oxygen into silicon, low resistivity silicon, MCZ silicon (collaborative effort)

Development of new material investigative techniques

- ✓ Transient Current Technique (electric field formation, effective trapping time)
- ✓ Developed now widely used Current-Deep Level Transient Spectroscopy (I-DLTS) technique
- ✓ Provide I-DLTS user facility to outside investigators and foster collaborations

Novel Detector Designs

- ✓ 3D-Trench Detectors
- ✓ Charge injected diode sensors
- ✓ 2D and 3D stripixel detectors

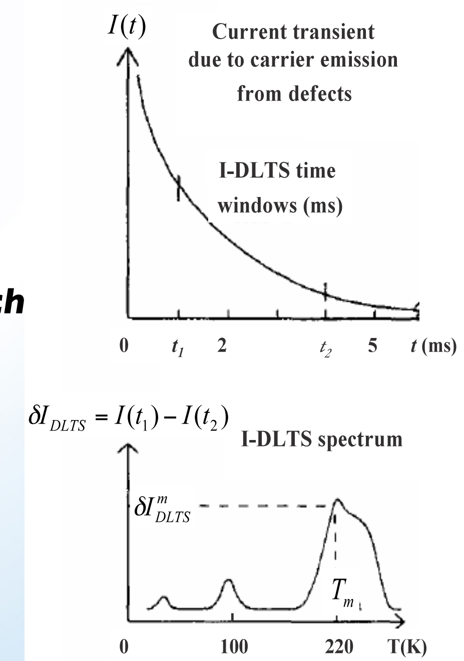
Involvement in collaborations dedicated to radiation hard detector research

- ✓ RD39: Cryogenic detectors for LHC (Z. Li Co-spokesperson)
- ✓ RD50: Rad hard semiconductor devices for very high luminosity colliders

History includes

- ✓ P-type Pixels for current CMS
- ✓ Large strips for proton-spin physics at RHIC (*PP2PP*)

I-DLTS



Materials Research to Increase Radiation Hardness:

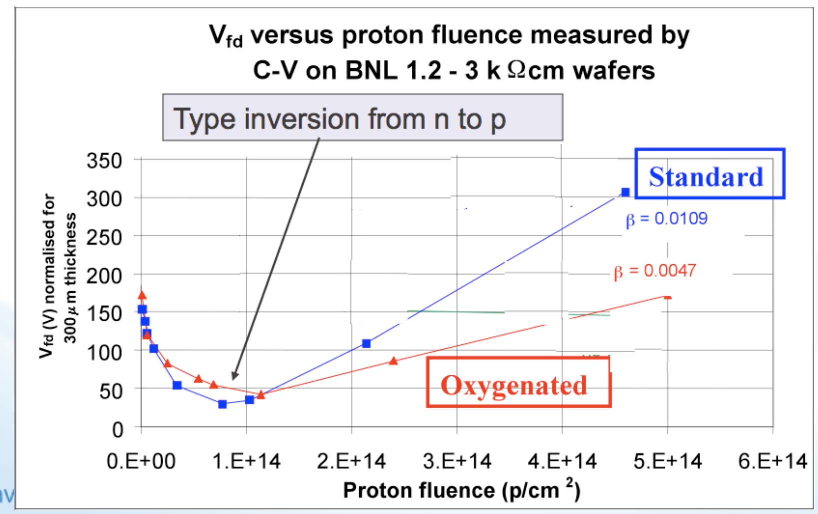
seek variants of initial silicon substrate that mitigate radiation effects

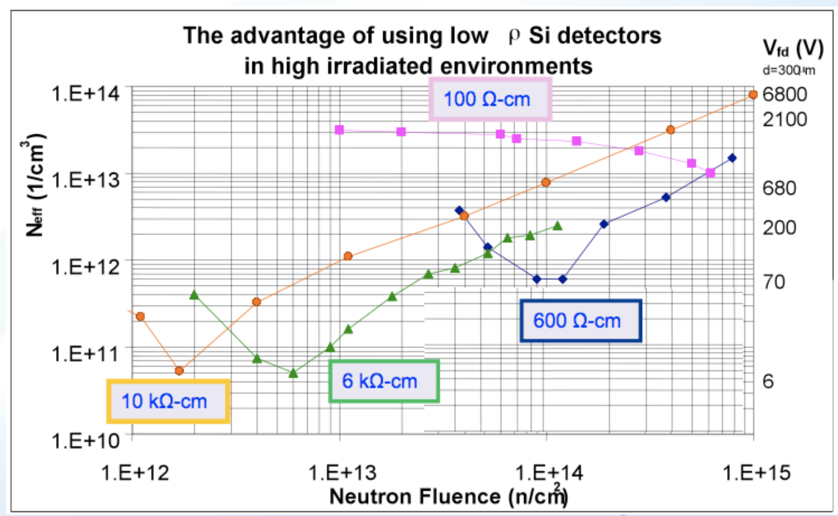
Effects of radiation damage on silicon

- Defects in the Silicon lattice act as fixed positive charge
- Turns n-type bulk silicon to p-type (known as type inversion)
- After inversion, increase in depletion voltage (and possible detector breakdown)
- General increase in leakage current (increased noise)
- Creates trapping centers for ionized charge

BNL innovations to mitigate radiation effects

- Pioneered introduction of oxygen to Float Zone silicon: oxygen getters defects slowing rate of increase of depletion voltage of post-inversion silicon with increasing radiation dose
- Demonstrated that gammas induce negative fixed space charge. Showed that in some radiation environments this may lead to detectors that survive extremely high fluence (e.g. ILC calorimetry).
- Proposed the use of low resistivity silicon (cheaper and more radiation resistant due to high intrinsic impurity levels). Low resistivity silicon may be used in conjunction with 3D detector designs





3D Trench Detector Concept

- At very high radiation doses (10^{16} neutron eq/cm^2), charge collection distance is limited by trapping to ~ 50 μm

- Typical standard 2D detector generates ionized charge through full thickness (~ 300 μm), but collects only ~1/6 signal (50/300).

- 3D detectors feature etched vertical electrodes that separate charge generation (proportional to detector thickness) from collection direction (electrical field transverse, electrode distances < trapping distance) for efficient charge collection

- Recent BNL proposed (patent pending) variant features isolated cells that has many advantages over competing 3D detector designs, e.g.

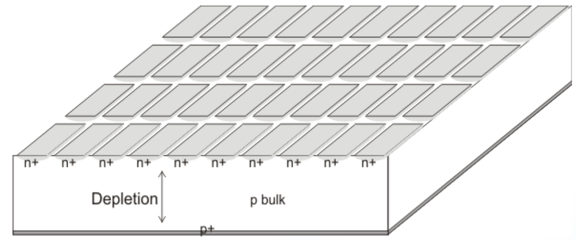
  --Single sided processing for significantly lower cost

  --Uniform electric fields for more efficient charge collection and greater breakdown resistance

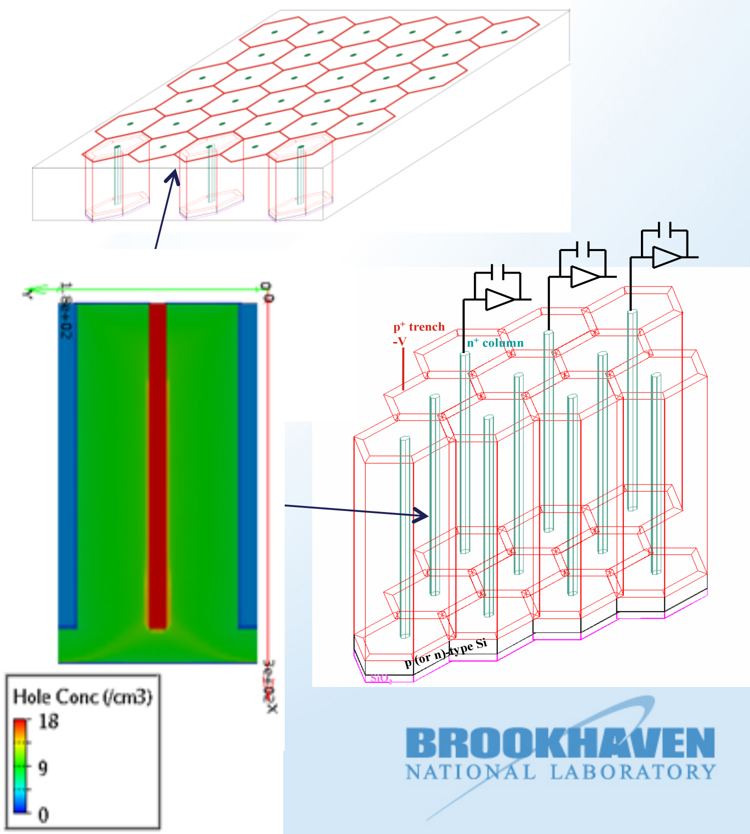
  -- Lower depletion voltages

- Concept highly promising and versatile; LDRD recently submitted to prototype concept.

Standard 2D Planar Pixel Detector



3D Trench Detector (Independent Coaxial Array Configuration)



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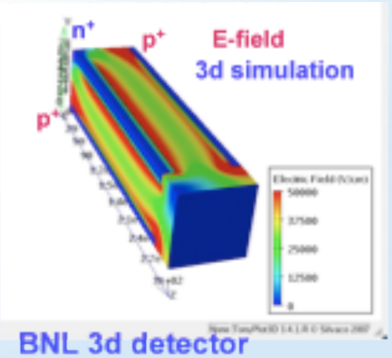
Near Term HEP Related Research Priorities

1. Develop and prototype 3D-Trench detector (funding permitting).

2. Charge Injected Diode detector development in collaboration with RD39

3. MCZ silicon material studies including process and radiation induced thermal donors

4. Studies of extended cluster defects in silicon



BNL 3d detector

Sensors for Astrophysics

- *KA15 core currently supported scientific personnel: W. Chen*
- *Other Scientific and Eng. Personnel: G.A. Carini, P. O' Connor, G. de Geronimo, J. Frank, I. Kotov, S. Plate, V. Radeka, P. Siddons*
- *Key Collaborators: J. Geary (Harvard), S. Kahn, K Gilmore (SLAC), C. de la Taille (LAL), B. Ramsey (NASA MSFC)*

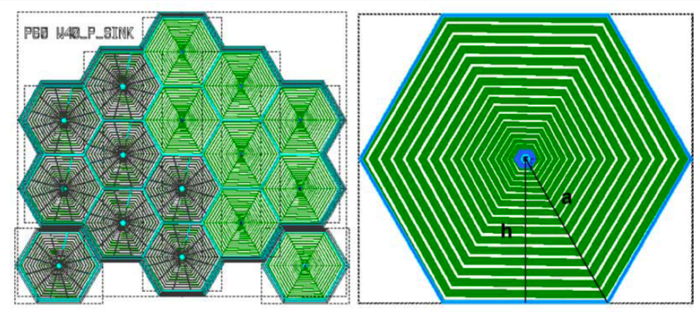
Expanding interest at BNL in research at the cosmic frontier

Instrumentation Division is developing new facilities for fabricating and characterizing detectors for astrophysics experiments

Major efforts in development

✓ CCDs for next generation focal plane array

✓ Silicon Drift Detectors and ASIC readout for spaceborne X-ray spectrometers

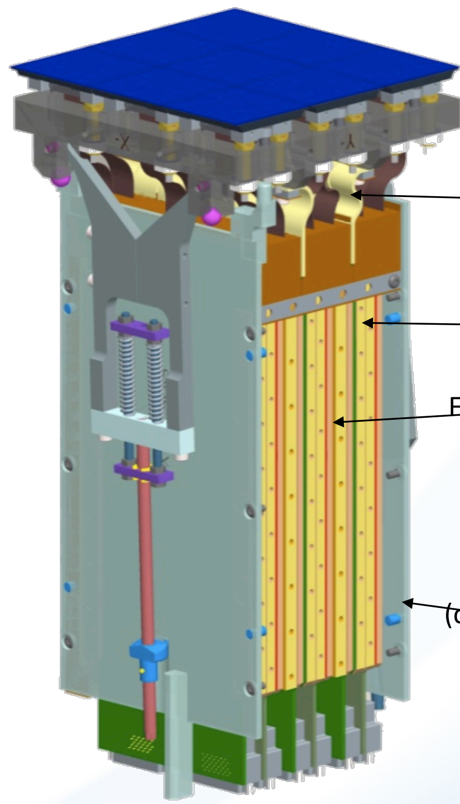


Development of CCDs for next generation focal plane arrays

Goals

- **Develop sensors and detector modules for constructing large area imaging mosaics for ground-based telescopes**
- Future experiments call for imaging focal planes with:
  - ✓ broadband (UV-IR) response
  - ✓ fine-scale pixilation (10μm)
  - ✓ low-noise (few electrons)
  - ✓ fast readout (1-2s)
- Overcome the limitations of current CCD sensors:
  - ✓ NIR response poor
  - ✓ Slow readout.
  - ✓ Excessive variability and low yield
- Partner with commercial vendors for developing fully depleted high resistivity CCDs

LSST fast, low noise 144Mpixel focal plane module



189 specially designed CCDs are assembled into 3x3 arrays (a "raft")

- Develop sensor simulation codes and construct advanced characterization labs to understand the fundamental properties of the sensors
- Take advantage of the Optical Metrology Lab at Instrumentation Division to develop precision mechanics and metrology for sensor mounting
- R&D on highly parallel, ASIC-based readout for fast frame rate

Photodetector R&D

- *No KA15 core currently supported scientific personnel*
- *Scientific and Eng. personnel: E. Muller, T. Rao, J. Smedley*

Goal

✓ Development of low noise, high resolution, fast photodetectors

Extensive scientific and engineering expertise in Instrumentation Division in laser and photocathode techniques

✓ directed at developments for accelerator applications (e.g. photo-injector for electron LINACs)

✓ Collab. with Physics Dept. for advanced R&D on photo-cathode materials to improve photon detector performance

Main areas of research

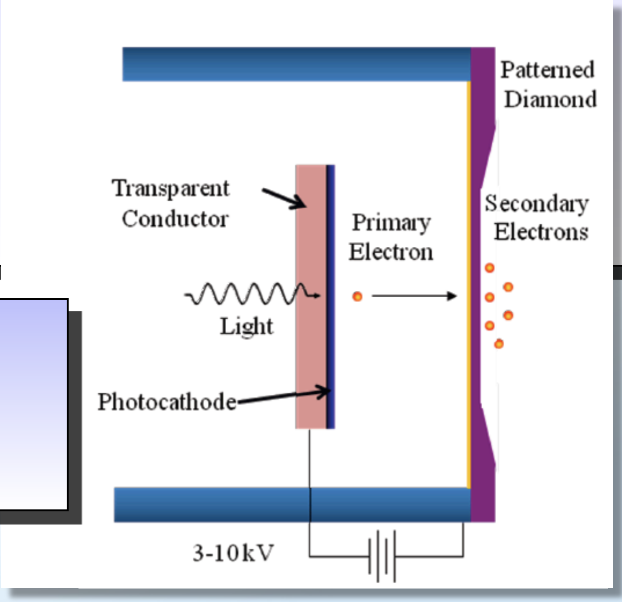
✓ Alkali cathodes

✓ Diamond amplified photocathodes

Hydrogen terminated diamond surface:

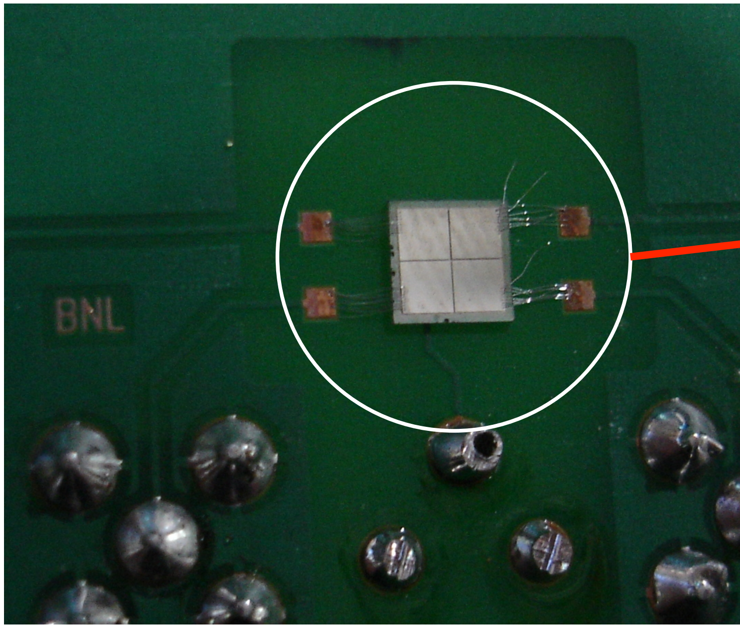
✓ High secondary emission coefficient

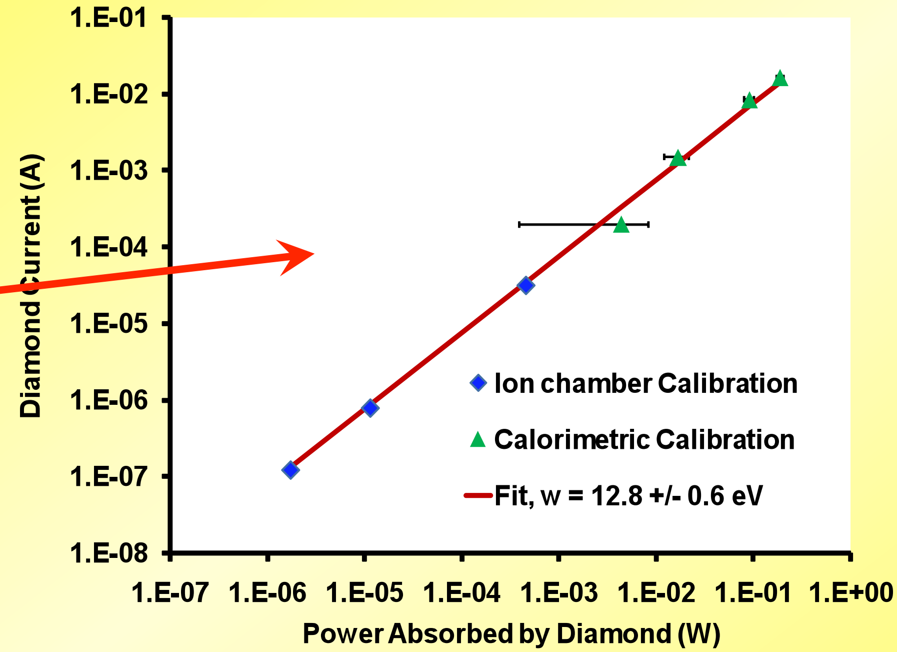
✓ Narrow energy spectrum of emitted electrons



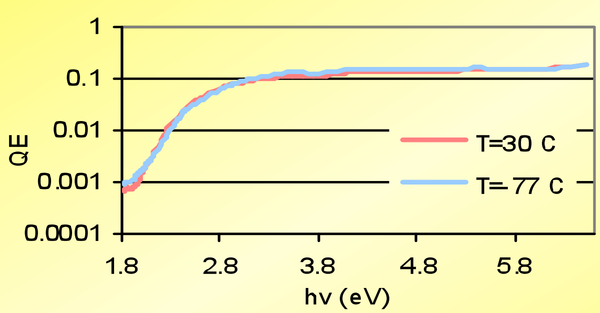
Photodetector R&D

Diamond Quad detector for x-ray flux measurement at NSLS





Response of diamond detector as a function of flux



Spectral response of CsK_2Sb cathode at room and cryogenic temperatures

Development and characterization of photodetectors for high power, wide dynamic range, low temperature operation

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Electronics and Signal Processing

- *No KA15 core currently supported*
- *Key Personnel: G. De Geronimo, A. Kandasamy, S. Li, N. Nambiar, P. O' Connor, S. Rescia, E. Vernon*
- *Key Collaborators: R. Yarema, G. Deptuch (FNAL), M. Newcomer (Univ. of Penn.), J. Cressler (Georgia Tech.)*

Instrumentation Division has an established worldwide reputation in low-noise ASIC design

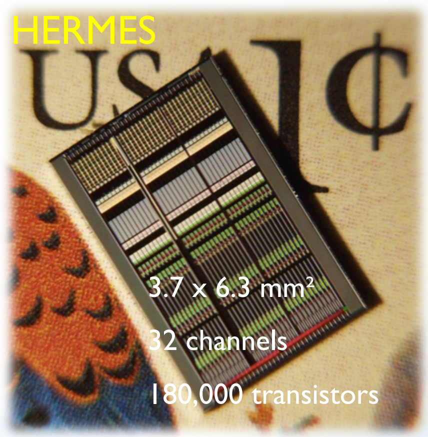
Developed more than 30 ASICs (~30 FTE effort) in the past 10 years for applications in:

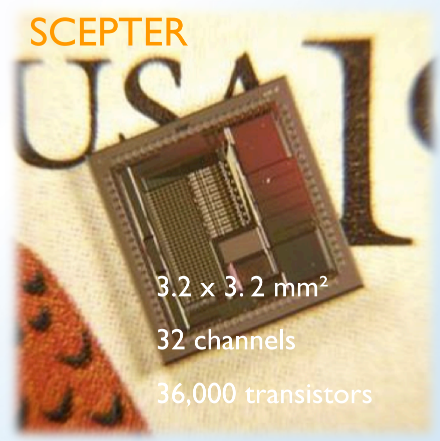
- ✓ Nuclear and Particle Physics
- ✓ Light Sources
- ✓ National Security
- ✓ Medical and Industrial Imaging
- ✓ Astrophysics

Areas of interest:

- ✓ SiGe integrated circuits
- ✓ 3D-integration technology
- ✓ CMOS ASICs R&D for cryogenic operations

ASICs for High-Rate Synchrotron Applications





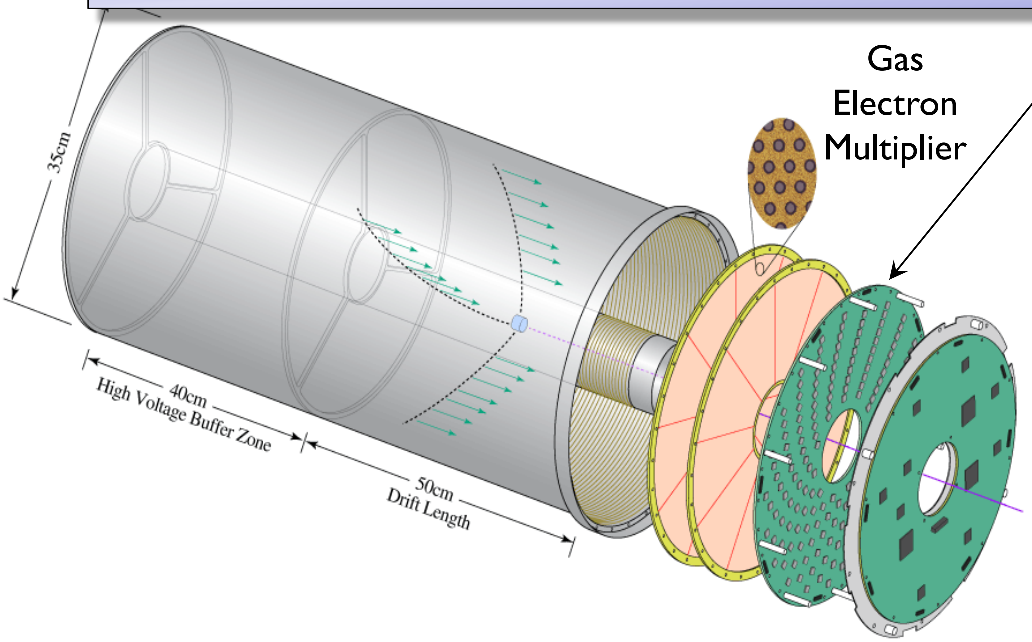
HERMES and SCEPTER are also used in several research, medical and industrial applications

Recent ASIC Projects

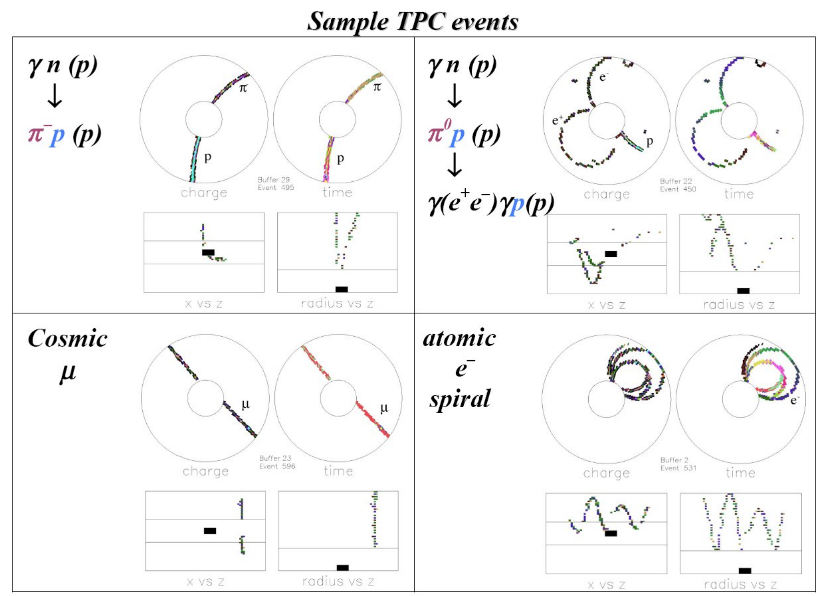
- STAR: CMOS front-end for silicon vertex tracker
- PHENIX: Front-end and flash ADC for time expansion chamber
- ATLAS: Cathode strip chamber, LAr calorimeter upgrade (SiGe), Muon Micromegas (CMOS)
- SLAC: Scattering experiments at Linac Coherent Light Source
- SNS: ^{3}He detector for small angle neutron scattering experiments
- LEGS: GEM TPC for laser electron gamma source experiments
- NSLS: Si detectors EXAFS and powder diffraction experiments
- NSLS & AUSTR. SYNCH.: High-rate, high-resolution micro-spectroscopy
- NSLS & NJIT: High-rate, high-resolution x-ray spectroscopy and holography
- NRL: Compton imager (DHS), x-ray navigation system (NASA)
- NASA: SDD-based XRS for elemental mapping in space missions
- MEDICAL and SECURITY: Micro-PET for RatCAP, PET-MRI, and wrist scanner, CZT-based PET, 3D position sensitive detector (UM, DoD, DHS), co-planar grid detector (LANL, DoD), portable gamma camera, prostate cancer imager (Hybridyne), eye-plaque dosimeter (CMRP)
- CRADAs: eV Microelectronics (CZT), Digirad (Medical), CFDRC (MAPS), Photon Imaging (Si) Symbol Technologies (Wireless)

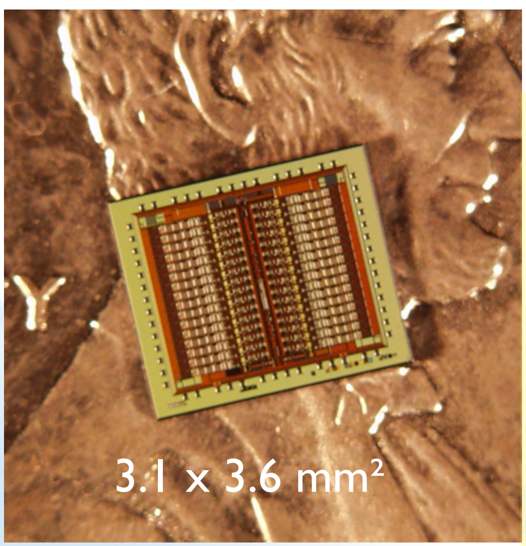
- Our patented sub-circuits are licensed to industries -

ASIC for Laser Electron Gamma Source TPC



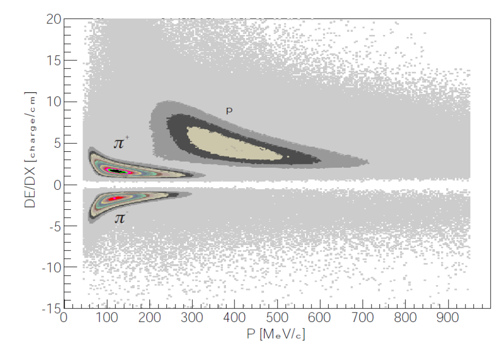
8000 anode pads read out in < 400 μs due to unique sparse readout





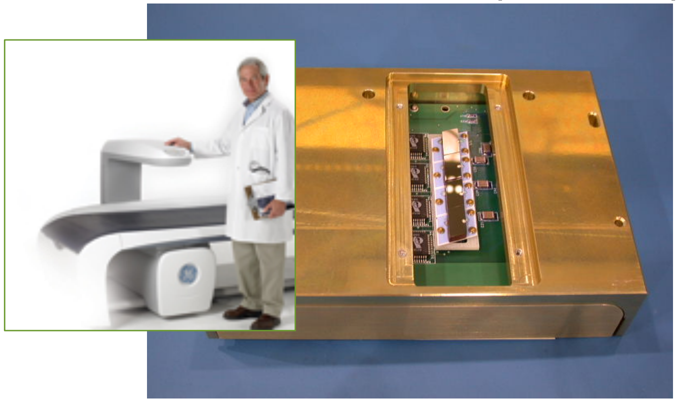
- 32 channels - mixed signal
- low-noise charge amplification
- energy and timing
- 230 e^-, 2.5 ns resolution
- neighbor processing
- multiplexed and sparse readout
- 40,000 transistors

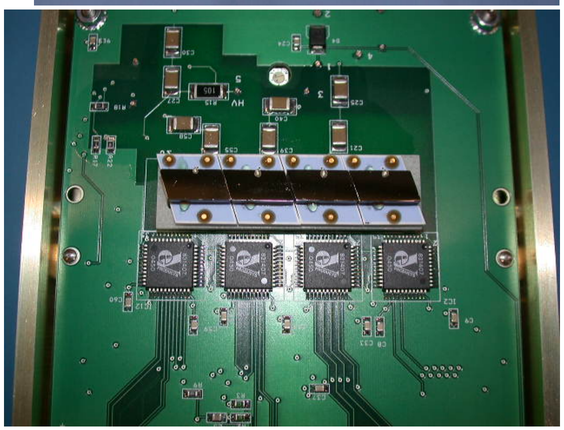
•used at CERN for MicroMegas measurements



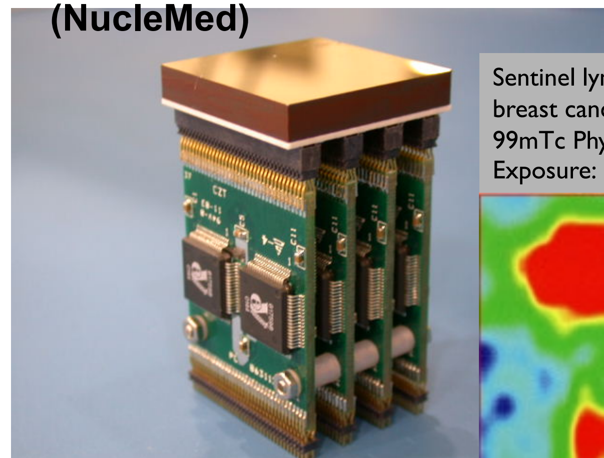
Examples of Commercial Applications

Bone Densitometer (GE Lunar)

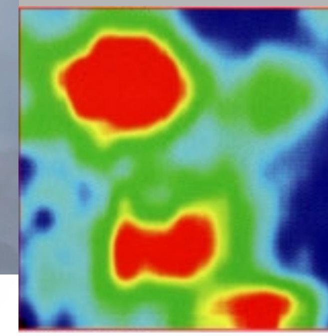




eZ Scope Compact Gamma Camera (NucleMed)



Sentinel lymph node of breast cancer
99mTc Phytate: 111 mBq
Exposure: 10 sec

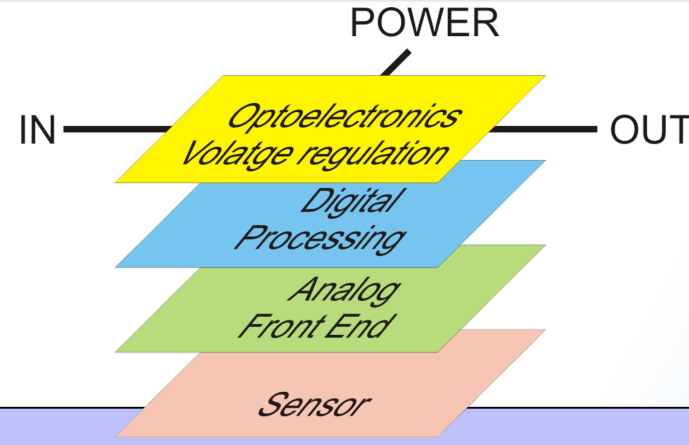


Solid State Gamma Imagers (Digirad)

Proxiscan (Hybridyne)
(in development)

3D Integration Technology

In the US a collaboration headed by FNAL is developing 3D integration using commercial process microelectronics suppliers.



Goals of BNL R&D program

- ✓ Direct bonding of ASICs to high-resistivity Si detectors fabricated in our Si detector development laboratory
- ✓ Develop a reliable, high-density bonding process that will not compromise detector performance
- ✓ Investigate undesired interactions of the electronics with charge-sensitive detectors

Realization of this technology will provide detector performance

- ✓ lower noise (low capacitance interconnect between sensors and front-end)
- ✓ increased per-pixel functionality for spectroscopic imaging and local time-tagging
- ✓ high fill factor for tiled detector arrays, since the front-end electronics will no longer need to be situated around the periphery of the sensors

SiGe Integrated Electronics for Extreme Environments

Technology allows flexibility in trading off critical circuit parameters such as noise, power and speed

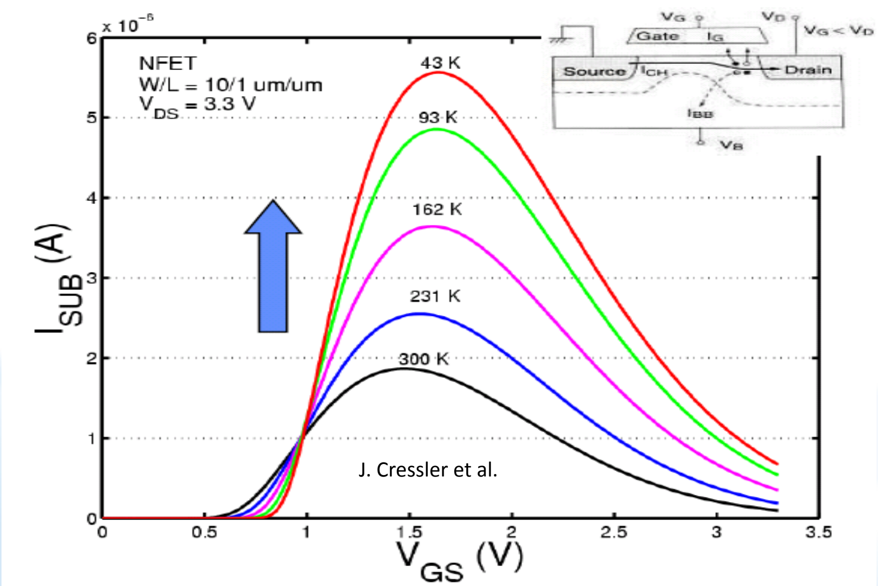
Radiation tolerant (both ionizing and single event) and works well at cryogenic temperatures

Degradation is due to impact ionization

charge trapped in oxide, interface generation → shift in V_{th} and g_m

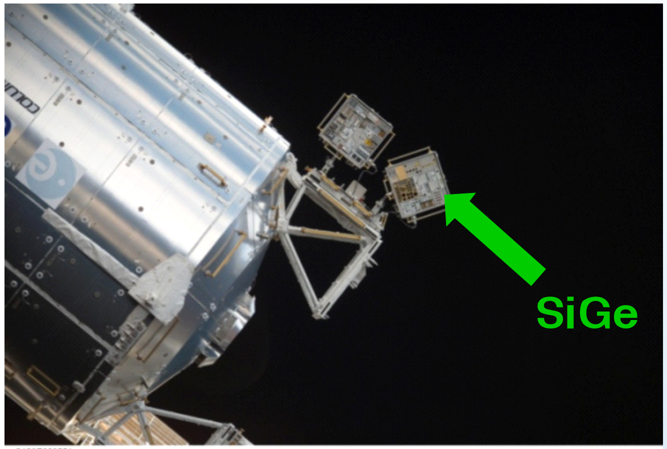
Substrate current is a monitor of impact ionization

- increases with drain voltage
- is higher in short channel devices
- has a maximum at $V_{GS} \approx V_{DS}/2$
- increases as the temperature decreases



Requirements: (e.g., Lunar, LAr)

- +120 °C to -180 °C cycling
- radiation hardness
- cryogenic operation



Recent NASA photograph of MISSE-6 after deployment, taken by the Space Shuttle Crew

Georgia Institute of Technology

J. Cressler et al.

Wide range of applicability:

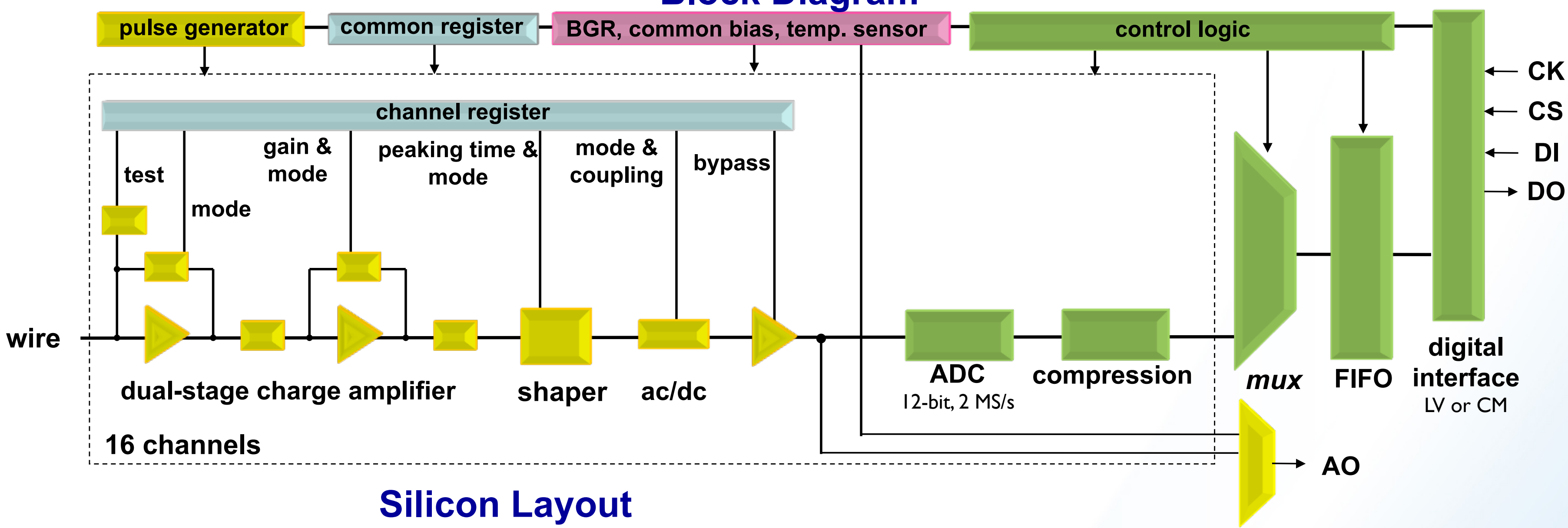
✓ Fast calorimetry

✓ Silicon strip detectors for future experiments

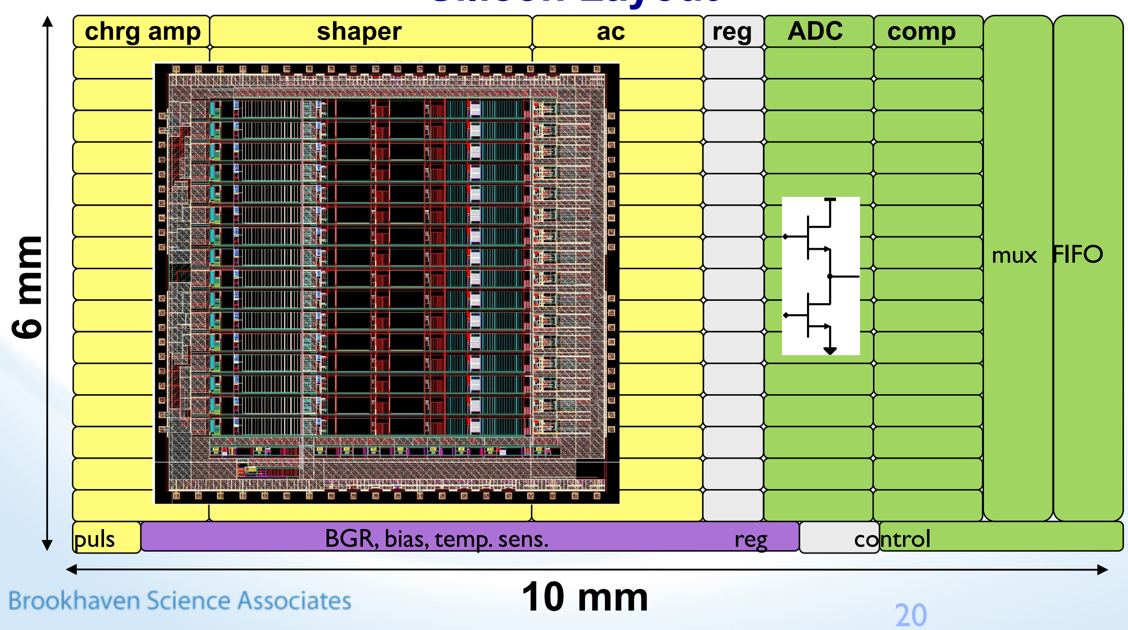
✓ Noble Liquid TPC

Front-end ASIC for LAr20

Block Diagram



Silicon Layout



- 16 channels - mixed signal
- charge amplifier (adj. gain)
- high-order shaper (adj. peaktime)
- ADC (12-bit, 2Ms/s)
- compression
- multiplexing and FIFO
- LV or CM digital interface
- test (calibration) pulse generator
- temperature sensor
- analog monitor
- Design for LAr operation > 20 years
- estimated power 10 mW/ch.

Microelectronics - Summary

- BNL has extensive experience in the design of low-power, low-noise, mixed-signal integrated circuits
- Mixed-signal integrated circuits and interfaces are compatible with low-noise front-ends
- The design process is defined and predictable, characterized by high yield and high reliability
- Long lifetime in cryogenic and radiation environments can be achieved using appropriate design techniques and processes
- ***ASIC challenges for future large detector systems***
  - Operation in extreme environments
  - Mixed analog/digital systems with low noise and high speed
  - High degree of data compression and multiplexing

Long Drift Noble Liquid Detectors

- *KA15 core currently supported scientific personnel: F. Lanni, W. Morse, C. Thorn*
- *Other scientific and eng. personnel: H. Chen, G. de Geronimo, J. Harder, D. Makowiecki, V. Radeka, S. Rescia, B. Vernon, B. Yu*

Goal

✓ To develop the basic understanding, techniques, and electronics to support the design of giant LAr TPCs for ν physics and PDK

Why a LAr TPC?

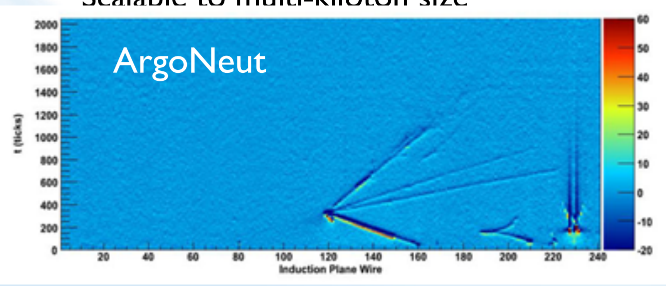
✓ High spatial and energy resolution

✓ Particle identification ($e/\gamma/\pi^{o}$) by dE/dx measurements (e/γ separation >90%)

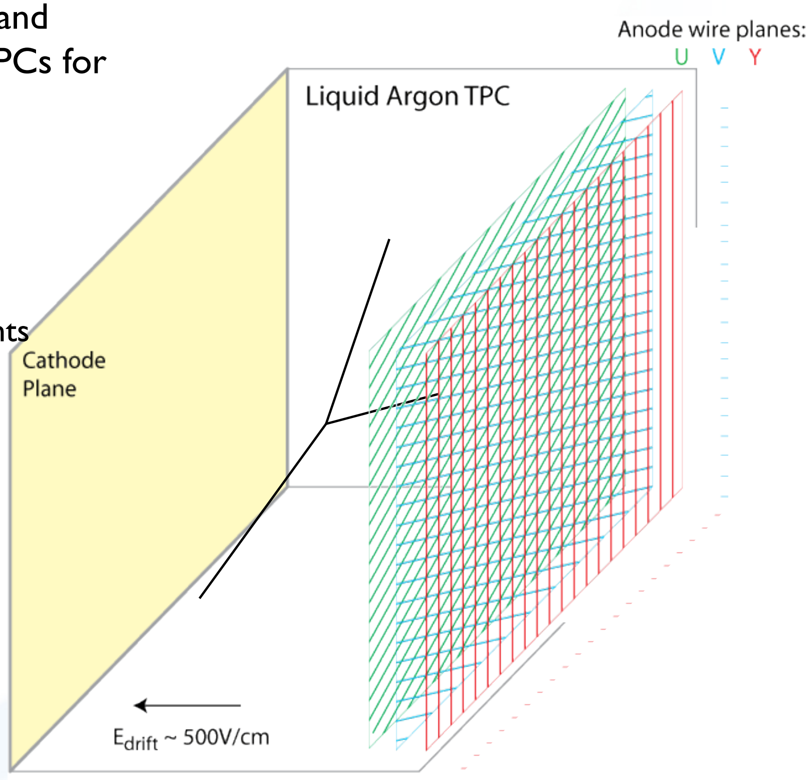
✓ Detailed 3D event reconstruction – 1Tera-voxel for 20 kT detector

✓ High detection efficiency and excellent background rejection

✓ Scalable to multi-kiloton size



How Does a LArTPC Work?



Scope of LAr R&D for LBNE

Readout Electronics

- ✓ ***low noise, cold (at signal source), on-board digitization, signal multiplexing***

Optical Readout for trigger

- ✓ ***scintillation process, optical absorption & scattering, cold PMT/APD, wavelength shifting***

Detector Studies and Optimization

- ✓ ***field cage design, readout plane design, signal formation***

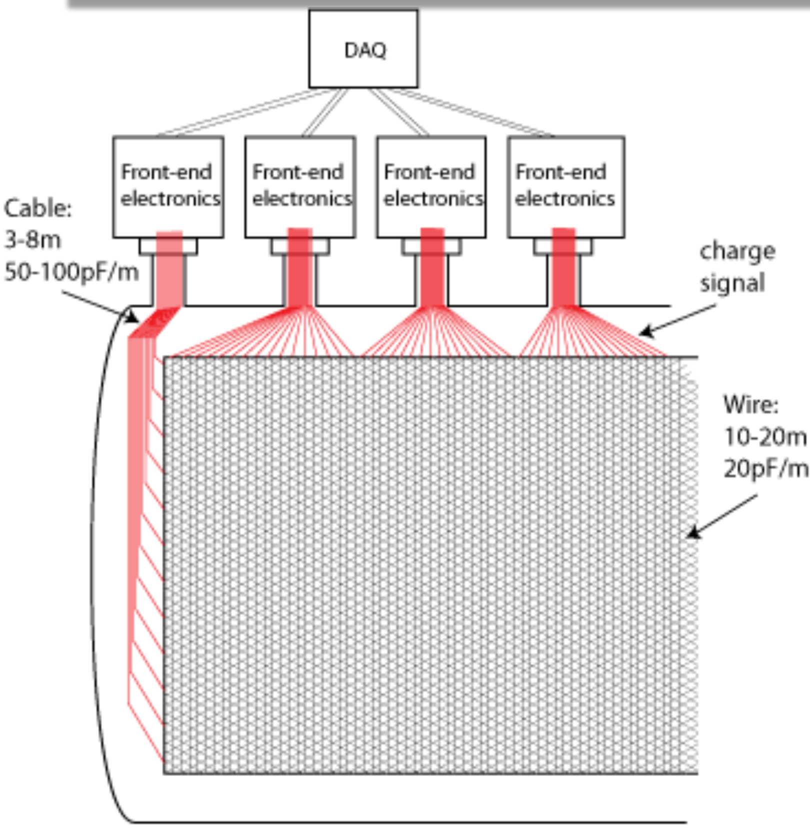
LAr properties measurements

- ✓ ***diffusion, attachment, recombination, VUV absorption***

Cryostat and Cryogenic System Design

- ✓ ***"membrane" cryostats***

LAr TPC readout electronics
The old way - ***Warm***

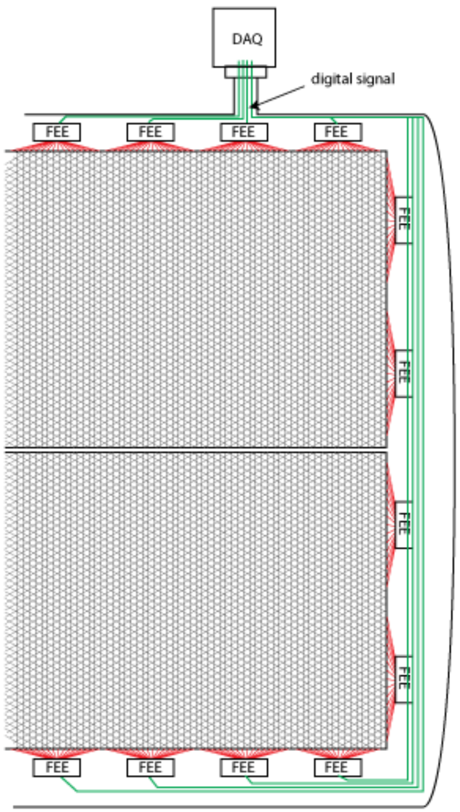


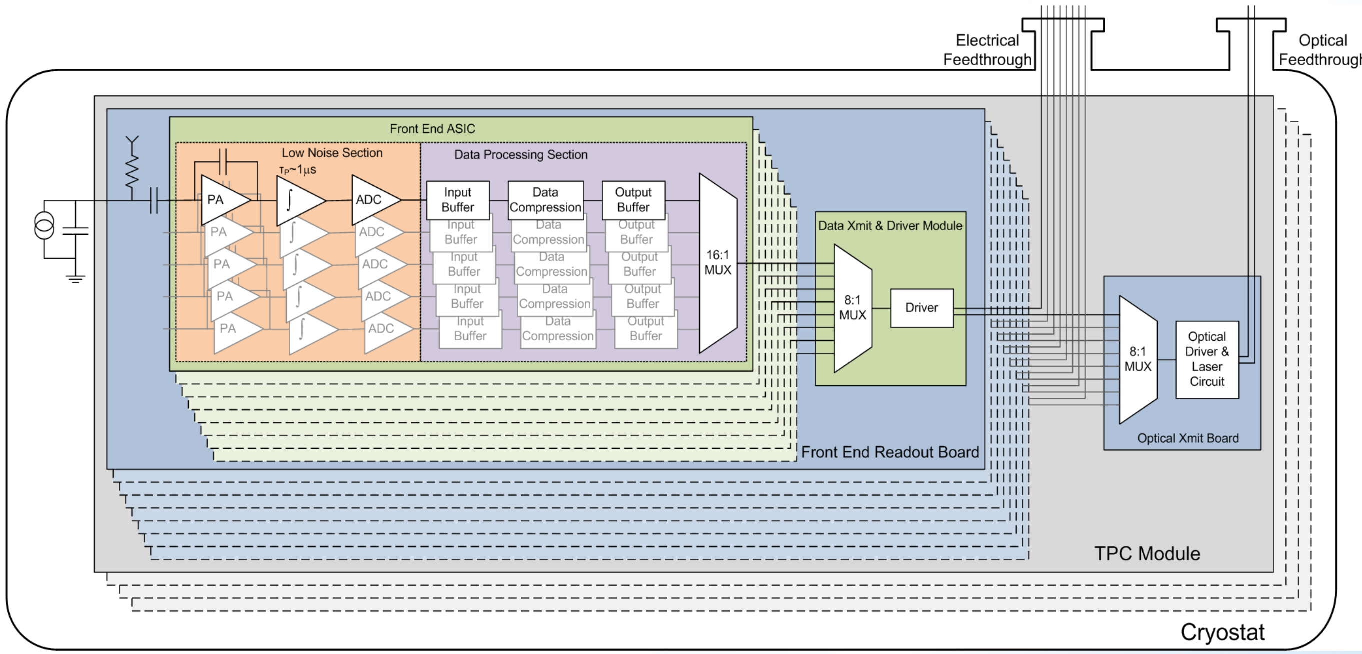
ICARUS T300 Module

Warm electronics requires

- ✓Long cables to preamp ⇒ Large noise
- ✓Many cables in LAr ⇒ Risk of LAr contamination
- ✓Many feedthroughs ⇒ Heat load & cryogenic risk
- ✓Complex assemblies & interconnects ⇒ Risk of signal loss

LAr TPC readout electronics
The new way - ***Cold***





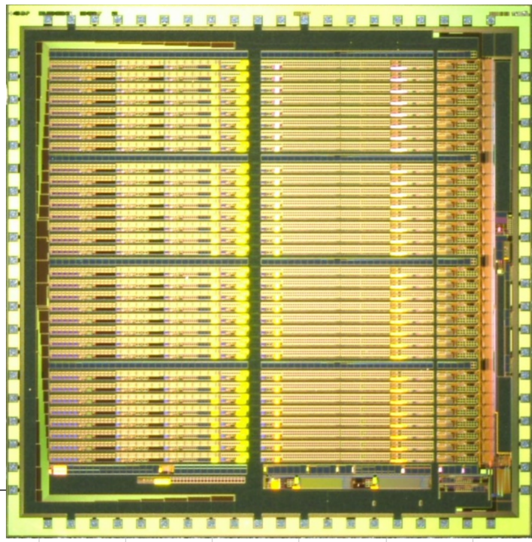
Cold electronics allows

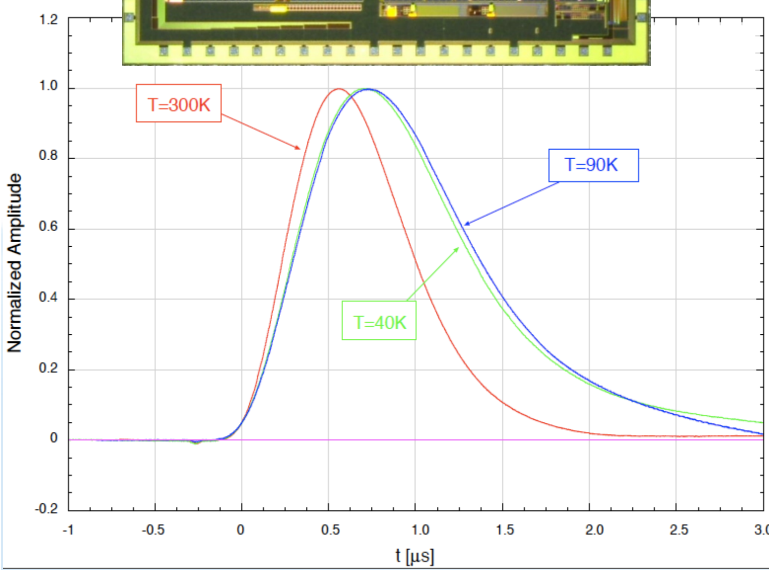
128x →   1024x →

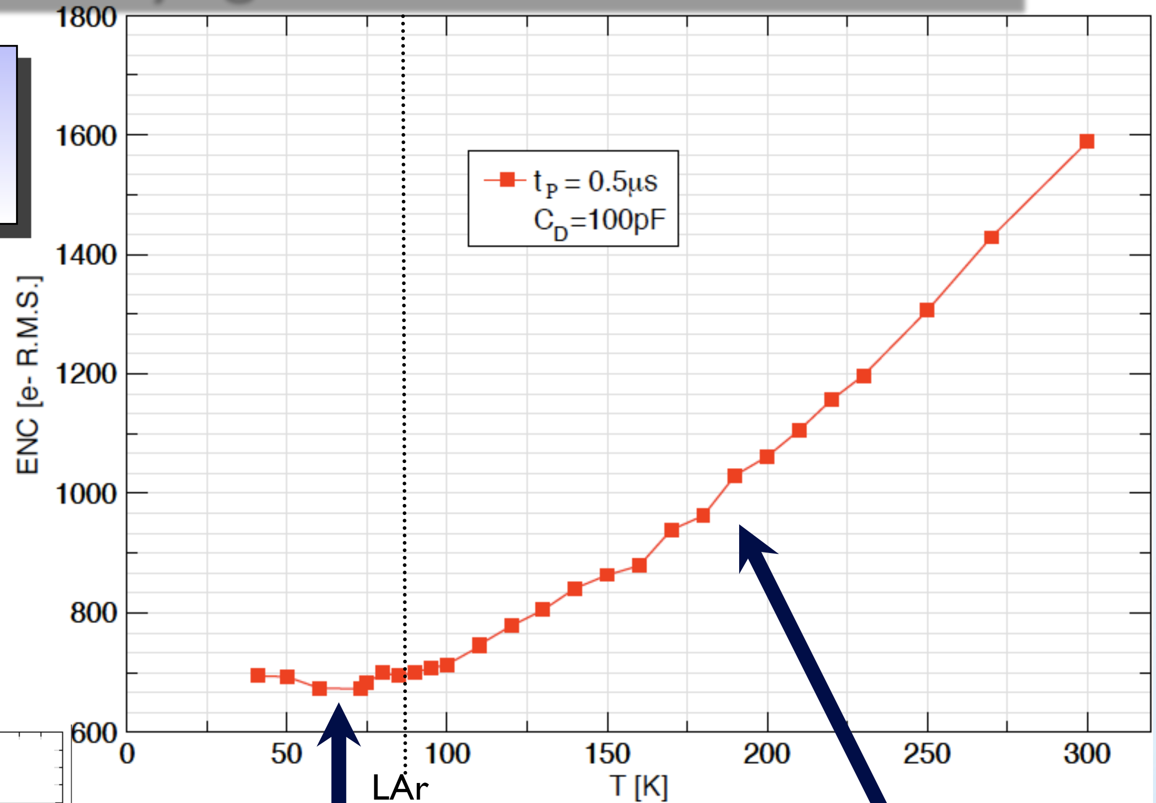
- ✓ Best SNR
- ✓ Few cables in LAr
- ✓ Few cryogenic feedthroughs
- ✓ Few interconnects & simple cabling
- ✓ **Scalability: since the electrode and cryostat design are decoupled from the readout design, *noise is independent of the detector volume.***

R&D on Cryogenic Readout

Preliminary measurements of an existing ASIC (TSMC CMOS 0.25μm process) designed for room temperature operation.







Then decreases due to impurity scattering as the temperature of the lattice is reduced compared to the electron temperature.

Bulk mobility and transconductance increase as temperature is reduced; noise decreases

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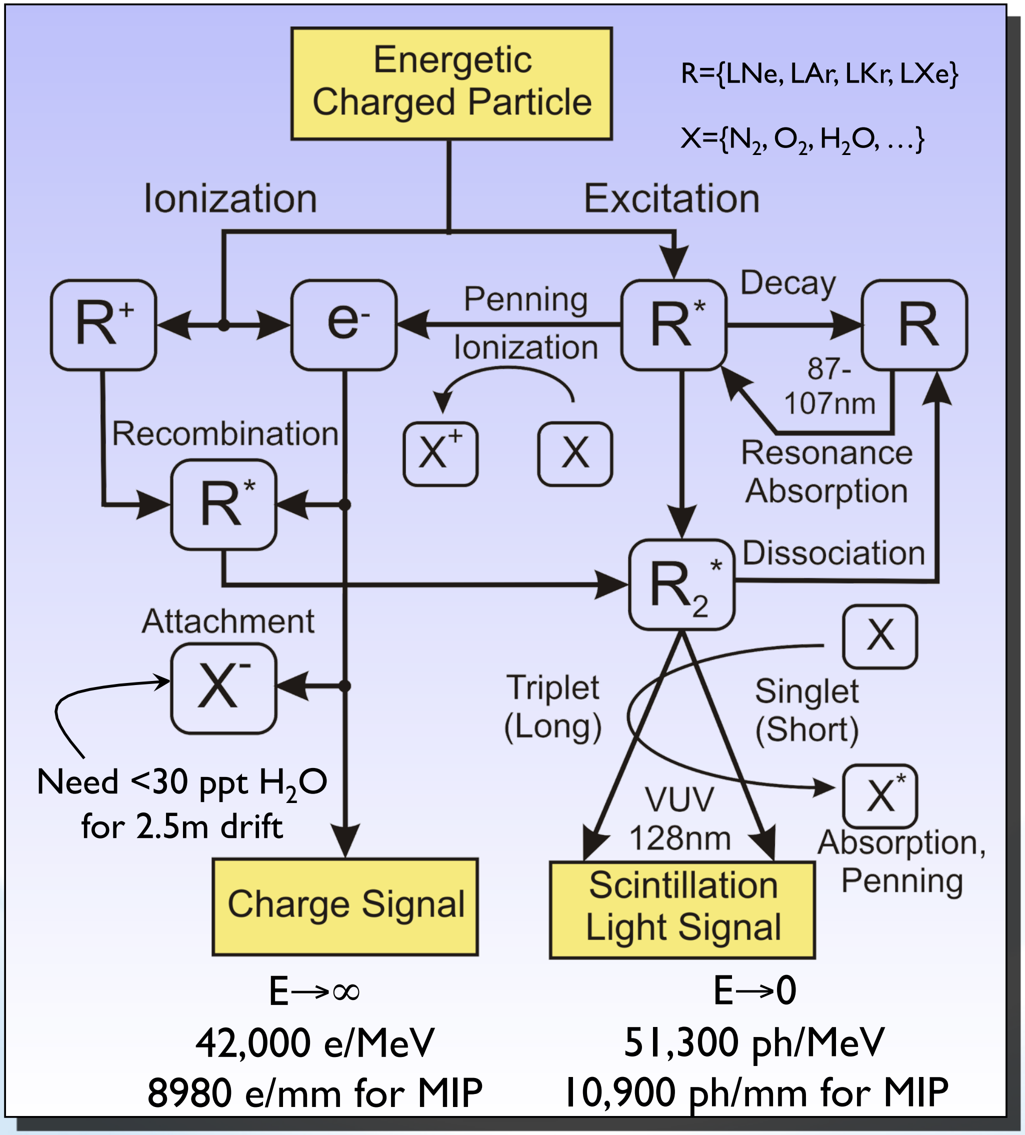
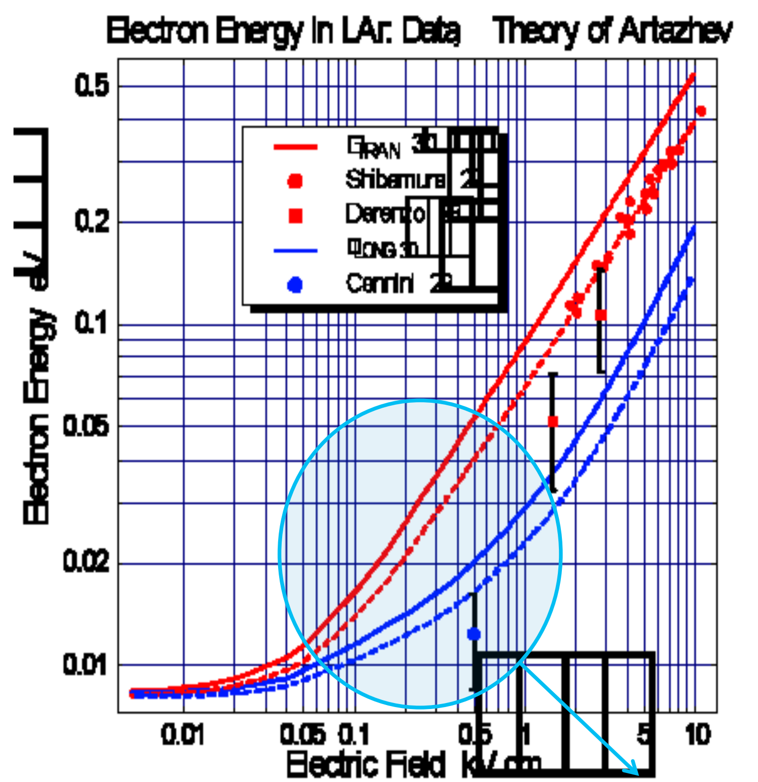
Properties of LAr – Response to ionizing radiation





~no data below 1.5 kV/cm

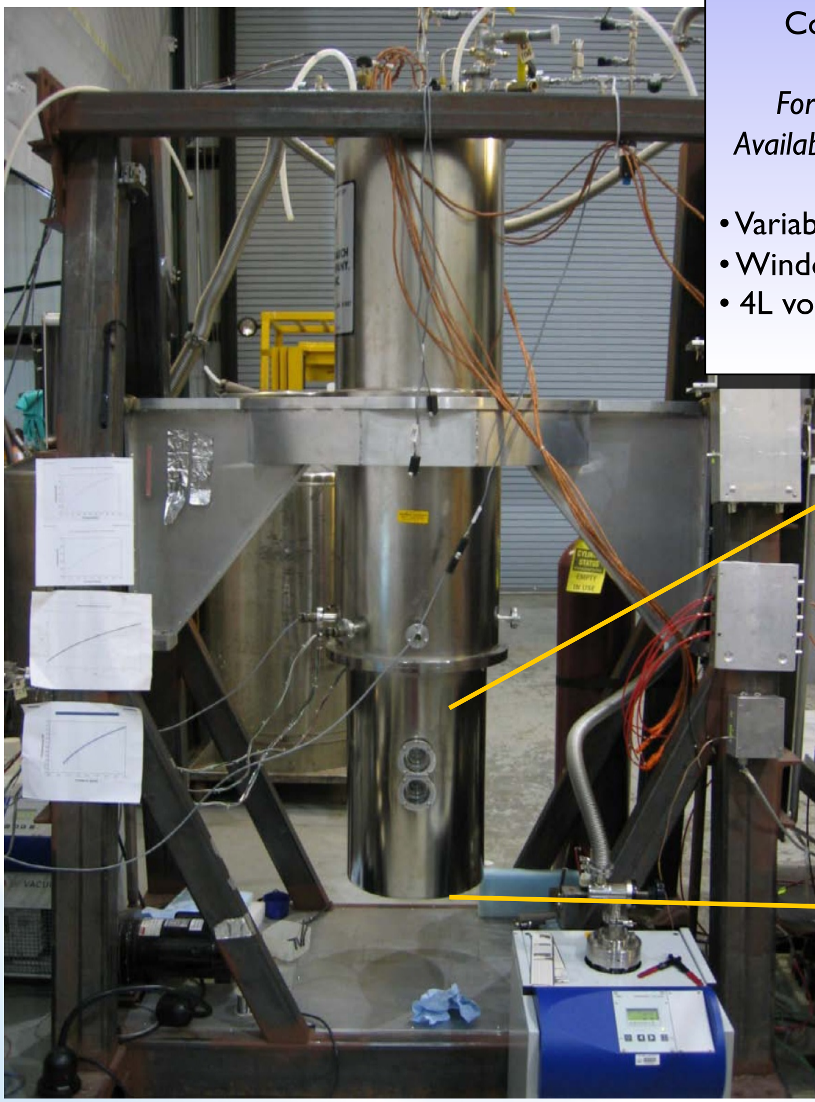
Relevant fundamental properties of LAr:

✓Electron Diffusion

✓Light scattering and absorption

✓Electron attachment

LAr Properties: Electron Diffusion



Columbia University eBubble Cryostat

Located at BNL

Formerly used for R&D on Supercritical Ne

Available for LAr R&D at end of eBubble program

- Variable temperature cryostat
- Windows for optical measurements
- 4L volume

$$\varepsilon_e \equiv \frac{eD_e}{\mu_e}$$

$$\sigma = \sqrt{\frac{2Dz}{\mathrm{v}}} = \sqrt{\frac{2\varepsilon z}{\mathrm{E}}}$$

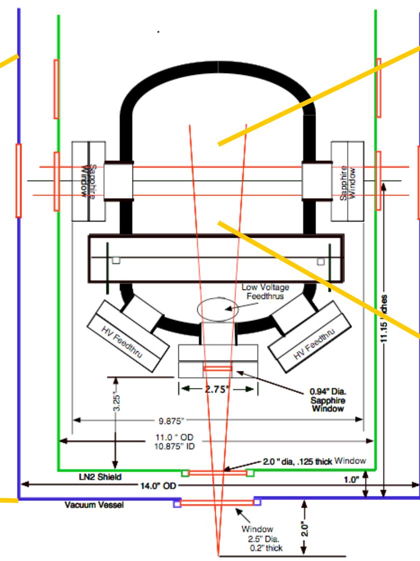
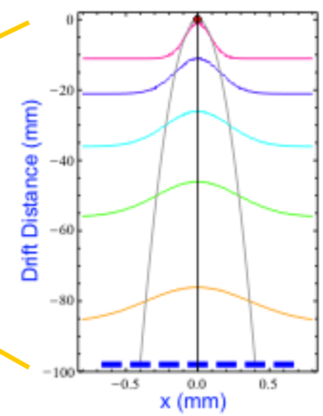
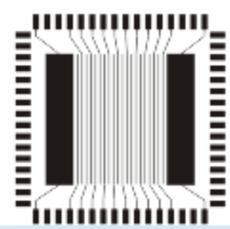


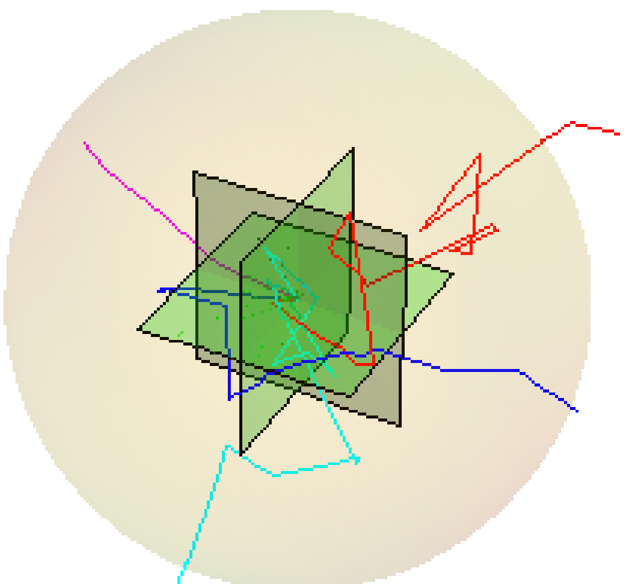
Fig. 2 - Position of Vessel Inside LN2 Shield and Vacuum Tank



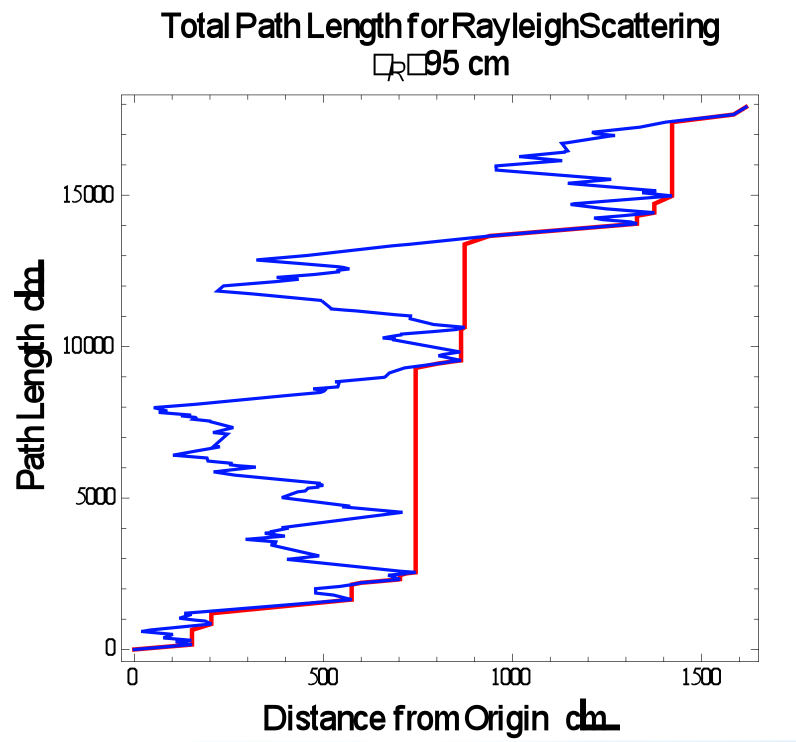


Rayleigh Scattering
of 128nm LAr Scintillation Light

Makes any attenuation worse



Four “typical” tracks
- Sphere has radius of 2.5 m
- Mean scattering distance: λ_R = 0.95 m
- Mean absorption distance: λ_A = 3.0 m for 100 ppb N_2



$$L_{PATH} = r + 0.47\ \text{cm}^{-1}\ r^2/\lambda_R$$

Transmission is

$\text{Exp}(-L_{PATH}/\lambda_A)$ = **0.24**

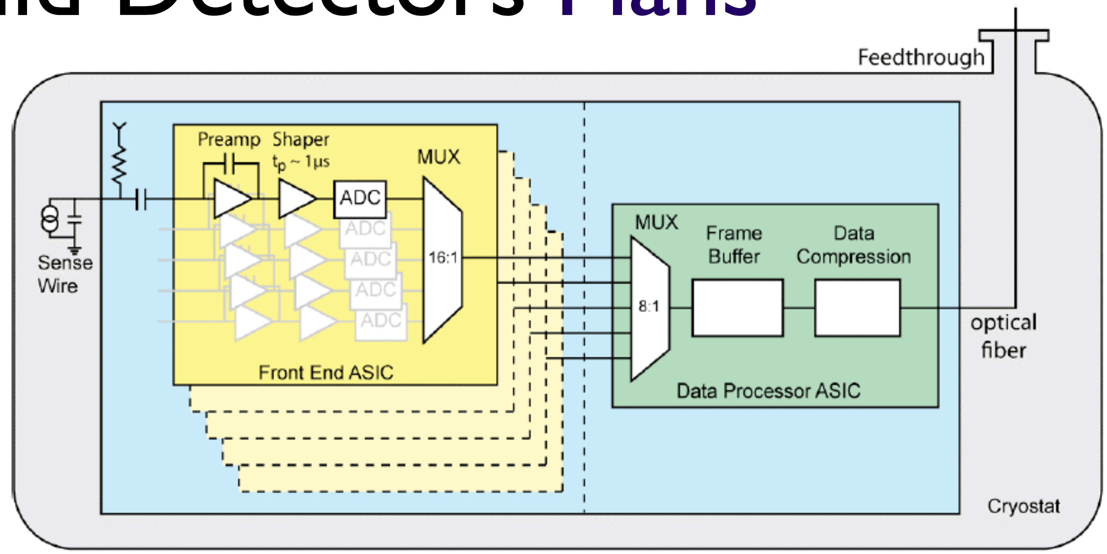
at 2.5m for λ_R = 0.95m & λ_A = 3.0m

Note: A small addition (500ppm) of xenon shifts the UV radiation to 178 nm, with λ_R = 8.2 m

Noble Liquid Detectors Plans

Cold Electronics

- Develop transistor models for cryogenic operations
- Characterize low frequency noise performance and address reliability issues of CMOS devices (hot carrier effects at cryogenic temperatures) from different available processes
- Develop a readout architecture with two stages of multiplexing (with optical interface)
- Developments circuits and tests at room and LN_2 temperatures
- *Collaboration with FNAL (R. Yarema, G. Deptuch) and Georgia Tech. (J. Cressler)*



Develop concepts for giant TPC detectors

- ✓ Optimization of TPC geometry (wire length, drift distance)
- ✓ Cold electronics design and Integration
- ✓ Complete characterization of the signal formation in a LAr TPC (diffusion, attachment, electrostatic design,..)
- ✓ Scintillation detection for t_0 and event triggers
- ✓ *BNL Physics Dept. and Instrumentation Div. actively involved in both MicroBooNE and LAr20 TPC for LBNE*

Bulk Micromegas

- *No KA15 core currently supported scientific personnel*
- *Scientific and Eng. personnel: V. Polychronakos, V. Tcherniatine, A. Gordeev, J. Fried, A. Kandasamy, G. de Geronimo, K. Nikolopoulos*

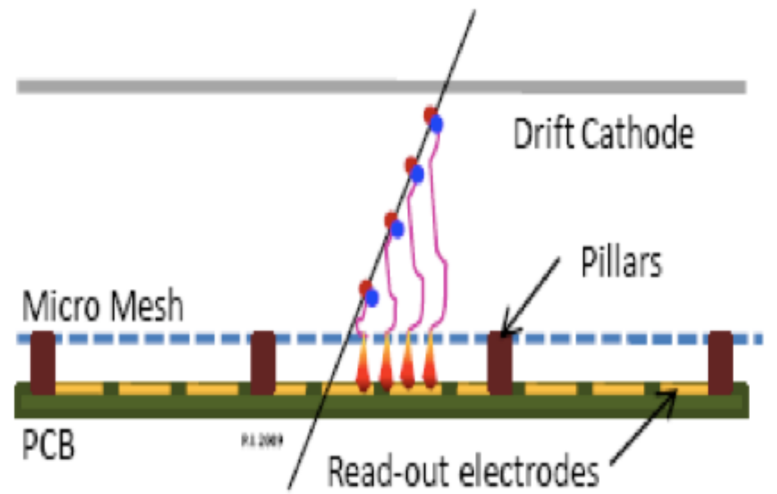
Advantages of Bulk Micromegas

- ✓ Large active areas achievable (~m^2)
- ✓ Standard Industrial PCB processing
- ✓ Excellent spatial resolution
- ✓ Capable of operating in high rate environments

Range of applicability: large area muon spectrometers (e.g. ATLAS upgrades of the forward muon chambers)

R&D Work

- ✓ Signal formation calculation, simulation and performance studies through testbeams at CERN (RD51)
- ✓ Partnership with industries for large area (>1m^2) detector structures
- ✓ Development of ASIC as front-end readout optimized for both position and time resolution



Precise control of amplification gap is achieved by insulating pillars fabricated with standard PCB laminating, masking, and etching techniques.

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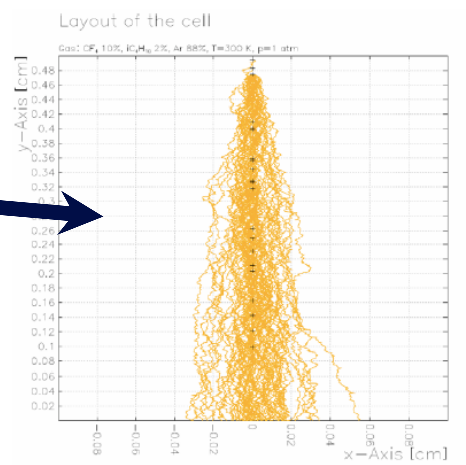
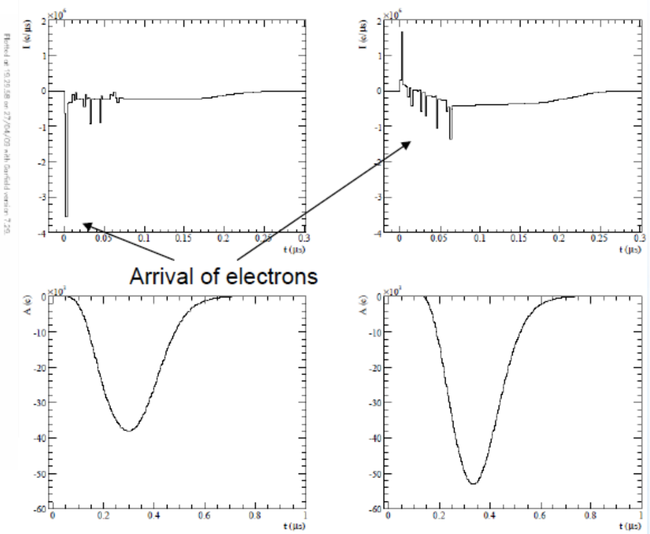
Current Activities

Ongoing R&D on:

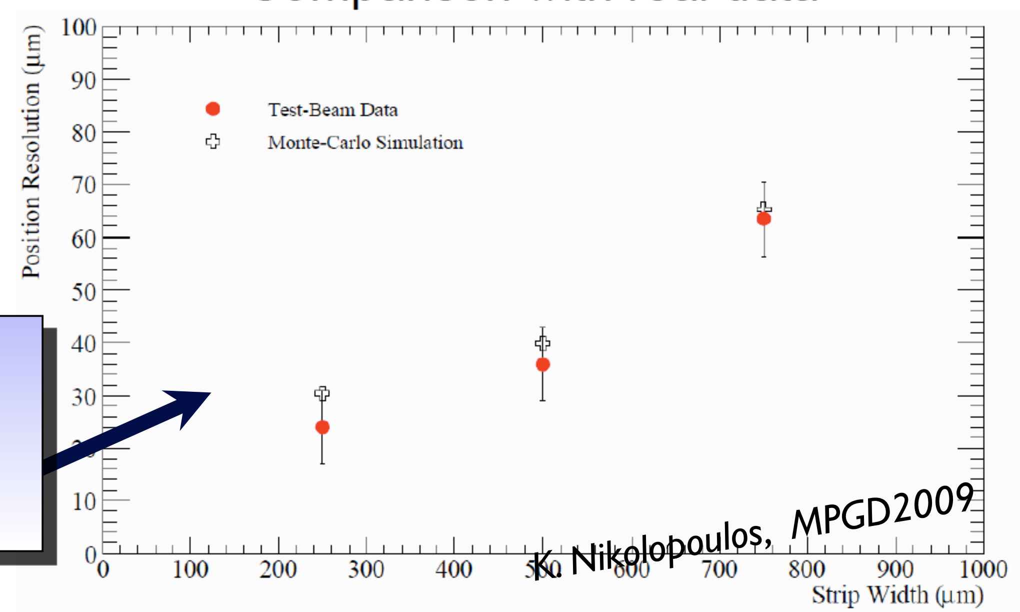
- ✓ Detector simulation & optimization based on Garfield
- ✓ Implementation of resistive interpolation and series resistance for spark protection
- ✓ Development of a Front-End ASIC matched to the unique aspects of Micromegas
- ✓ Operation of the device in TPC mode



Drift of ionization electrons from GARFIELD



Comparison with real data



K. Nikolopoulos, MPGD2009

Simulation validation through test beam measurements

Liquid scintillators for large-scale physics

- *KA15 core currently supported scientific personnel: M.Yeh, P. Sinha*
- *Scientific personnel: M. Diwan, R. Hahn, D Jaffe*

- **World-class expertise in the BNL Chemistry Dept. in low background counting, organic scintillators and, in particular metal loaded organic scintillators**.
  - ✓ Interest for neutrino and neutron detectors.
- Laboratory developed for the investigation of optical characteristics of a large variety of liquid scintillators:
  - ✓ PC, PCH, DIN, PXE, LAB
  - ✓ **Metal loaded liquid scintillators and water-based scintillators** with high light yield, long attenuation length and low flammability
  - ✓ Absorption and emission spectra, extinction length, dependance on purity level, concentration of fluors and wavelength shifters, environmental factors (e.g. temperature, humidity, exposure to air)
  - ✓ **Capability of purifying and synthesizing materials in-house and of controlling the chemical processes.**
- Collaboration between Physics and Chemistry Depts. at BNL

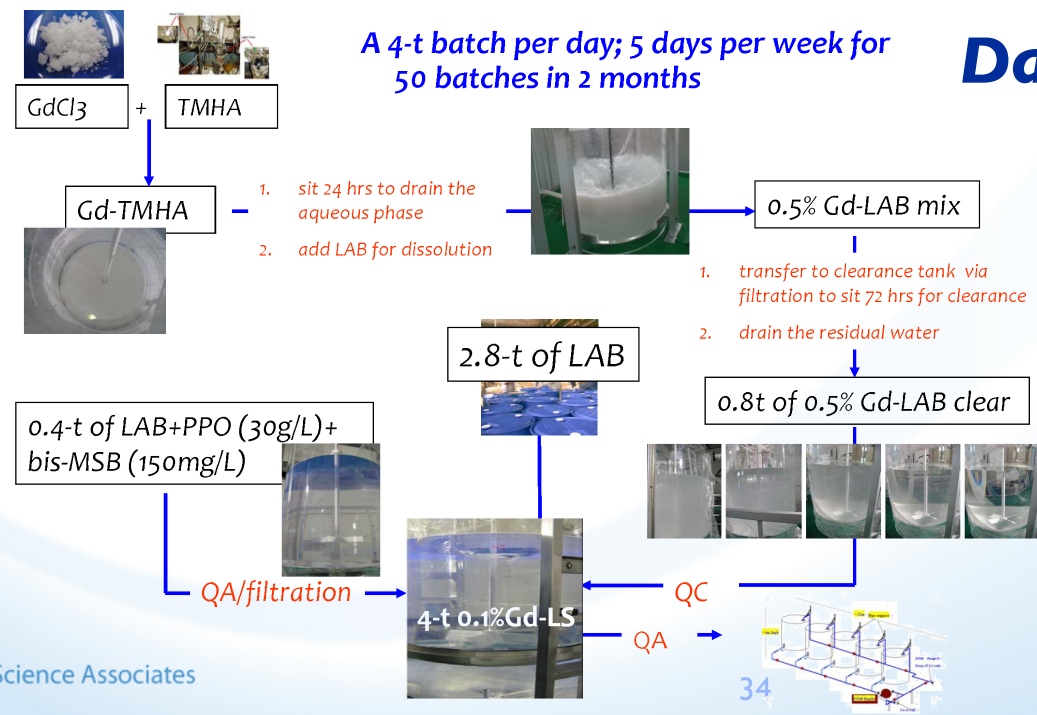
Metal loaded liquid scintillators

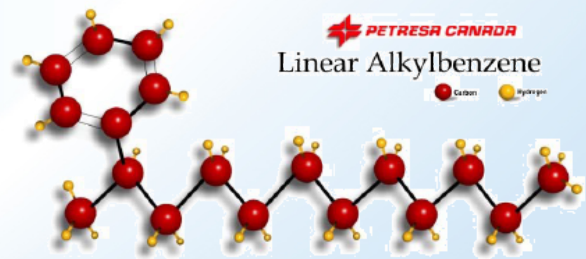
Development and production of Metal-loaded Linear Alkyl Benzene (LAB) based liquid scintillator (LS) for neutrino experiments

- ✓ Daya-Bay uses 200 tons of Gd-loaded LAB
- ✓ SNO+ uses 1 KT of Nd-loaded LAB
- ✓ LENS uses 125 tons of In-loaded LAB

Study of optical properties as a function of purity levels and of metal concentration

Daya Bay Gd-LS production





linear alkyl benzene (LAB) is an intermediate in detergent production

Water based liquid scintillator

Develop a W-LS to be used as energy spectrometers in large-scale physics experiments

Replace the hundreds to many tons of unloaded or metal-loaded organic liquid scintillators to provide:

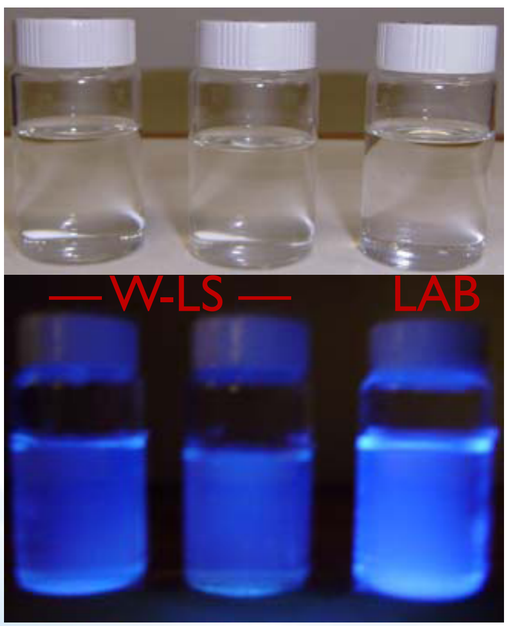
- ✓ simpler sensitive detection medium
- ✓ fewer compatibility problems
- ✓ cost savings

Non-linear photon production plus superior water attenuation length makes it possible to detect physics below Cherenkov threshold

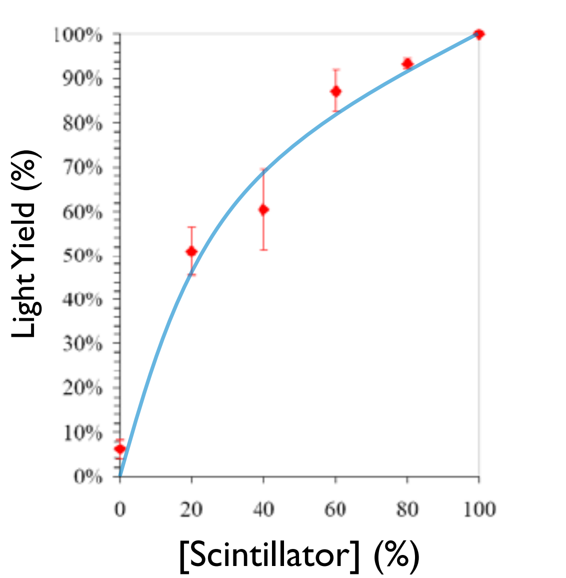
- ✓ K^+ PDK channel becomes accessible

VIS

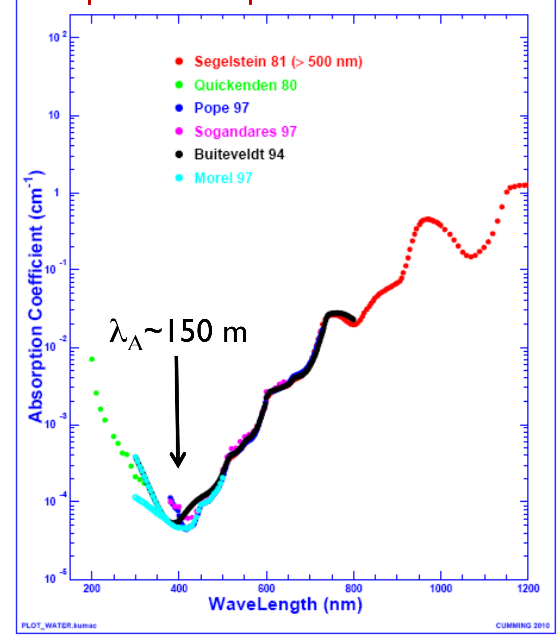
UV



Low concentrations give large yield



Optical Absorption of Pure Water



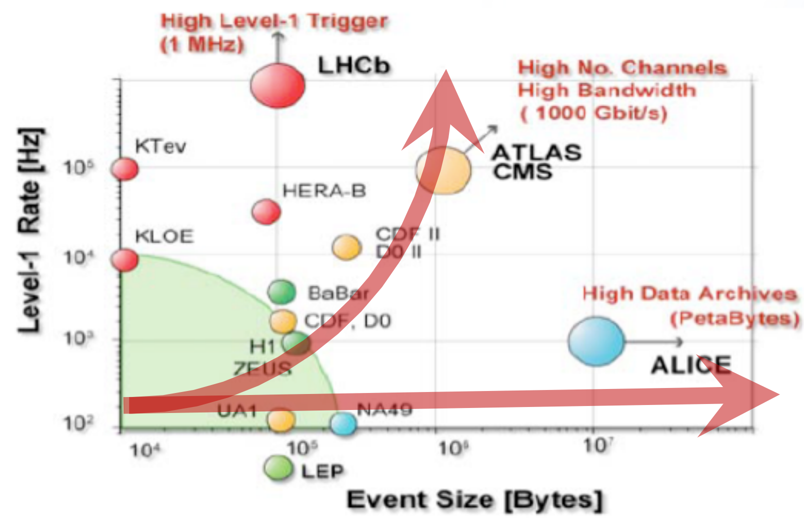
High Rate Data Acquisition and Trigger Systems

- KA15 core currently supported scientific personnel: F. Lanni, H. Takai
- Other scientific and engineering personnel: H. Chen, J. Fried, J. Mead

Motivation

HEP experiments historically demand increasing data throughput. From Tevatron to LHC by a factor of ~1000

Increasing energy and luminosity also challenge DAQ design. Radiation hardness, high detector occupancy, signals pileup, …



R&D Objectives

Development of high channel density data acquisition for high data throughput (> 1Tbyte/second) and harsh environments.

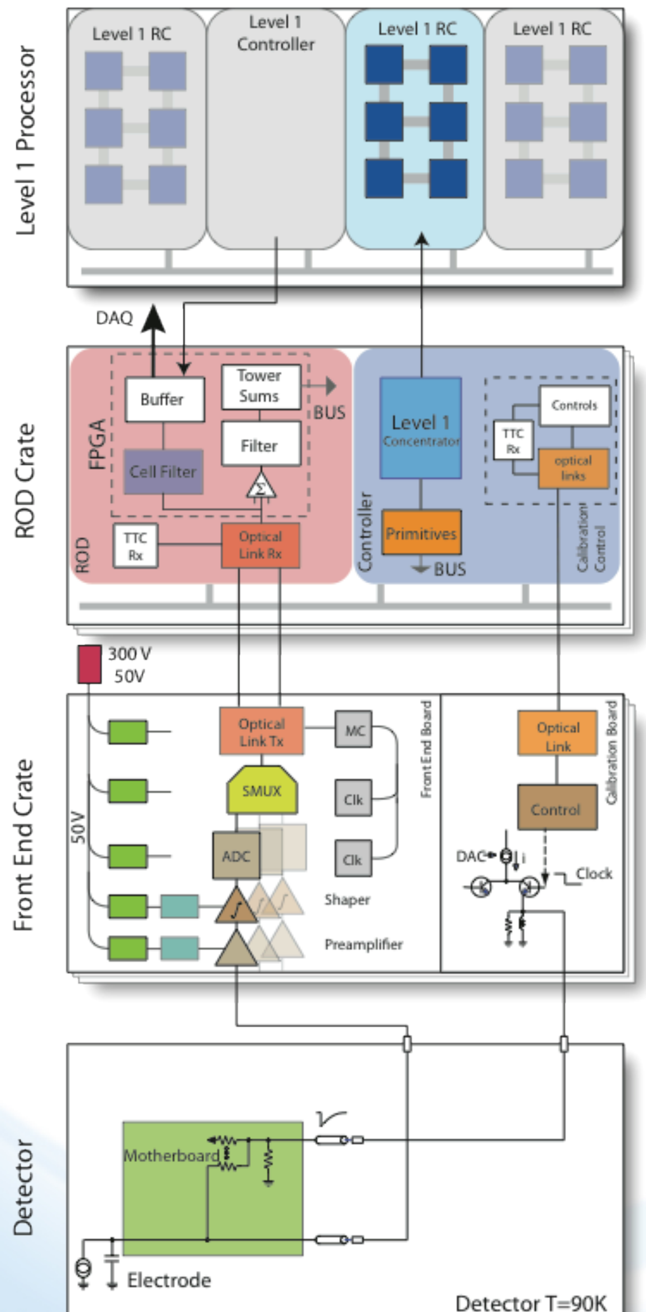
Development of high efficiency and low latency real time signal processing for high data throughput characterized by large multiplicities and pile-up.

Development of real time processors based on reconfigurable computing for identification and reconstruction of clusters, tracks, and jets; discrimination of e and γ; and calculation of missing E_T.

Synergy and Benefits

The objectives are common to HEP detectors including large neutrino detectors.

High throughput computing technology is exportable other fields: high resolution PET/CT, sky surveys with large telescopes, imaging in 3rd generation synchrotron radiation facilities.



High Rate DAQ and Trigger Generation

Model System

Level 1 Trigger Processor

Algorithm development for cluster finding, e/g separation
Reconfigurable computing for event reconstruction and missing E_T estimation
Cross board communication protocols with low overhead

Signal Processing R&D

Optimal filtering techniques for high rate environment
Adaptive filtering implementation on FPGA
Algorithm development for high multiplicity noise reduction.

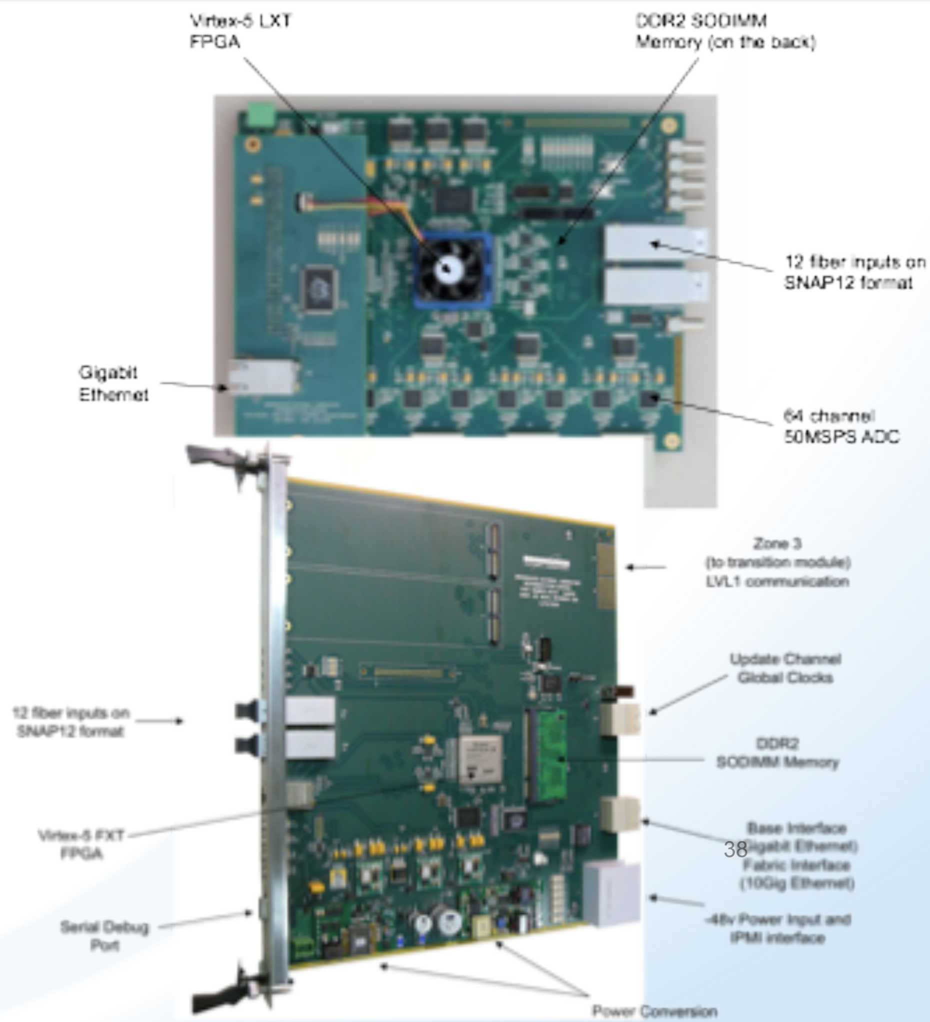
High Data Throughput/Detector Interface R&D

Parallel optical links up to 120 Gbps
Coding schemes for error correction
Low latency lossless data compression algorithms
High speed FPGA serializers
High speed serial busses
High density boards for 1 to 10 Tbps data transmission

High Rate DAQ and Trigger Systems

Current Activities

- High Density Interconnects
- High speed digitizer and signal filtering in FPGA based DAQ boards
- Real Time processing of large data throughput links
- Development of boards in industrial standard packaging for telecommunication (ATCA)



Detector R&D

FY10 Effort in FTE

Funding / activity	Noble Liquid Systems	SI Detectors	H2O Cerenkov & LS	Microelectronics & high rate DAQ	Sum
KA1503	**2.2**	**1.7**	**0.9**	**0.0**	**4.8**
KA1101 & 1301	0.0		0.4	0.4	0.8
Projects	2.0	0.2	0.4		2.6
LDRD, etc.	0.8				0.8
Instrumentation	2.0	2.0	0.2	4.5	8.7
Totals	**7.0**	**3.9**	**1.9**	**4.9**	**17.6**

Summary

Diversified interests in generic detector R&D reflect the Lab's expertise and multi-disciplinary nature

Unique facilities and scientific and technical resources provide a base of specialized support for physics programs

- ✓ Instrumentation Division is the fundamental key for supporting a broad range of programs in detector R&D

HEP programs have been advanced by and continue to benefit from Generic Detector R&D investment in

- ✓ Silicon sensors
- ✓ Electronics and signal processing
- ✓ Noble liquid detectors
- ✓ Liquid scintillators